GEOLOGICAL SURVEY OF NEW JERSEY.

ANNUAL REPORT

OF THE

STATE GEOLOGIST

FOR THE YEAR

1892

TRENTON, NEW JERSEY:
THE JOHN L. MURPHY PUBLISHING COMPANY, PRINTERS.
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CONTENTS.

LIST OF ILLUSTRATIONS.

MAPS.

PLATES.

FIGURES.

BOARD OF MANAGERS.

His Excellency Leon Abbett, Governor and *ex-officio* President of the Board........................Trenton.

I. CONGRESSIONAL DISTRICT.

John Clement..Haddonfield.
Clement H. Sinnickson................................Salem.

II. CONGRESSIONAL DISTRICT.

Emmor Roberts..Moorestown.
Henry S. Little..Trenton.

III. CONGRESSIONAL DISTRICT.

William H. Hendrickson..............................Middletown.
(Vacancy.)

IV. CONGRESSIONAL DISTRICT.

Augustus W. Cutler....................................Morristown.
George Richards..Dover.
Thomas Lawrence*......................................Hamburgh.

V. CONGRESSIONAL DISTRICT.

(Vacancy.)
(Vacancy.)

VI. CONGRESSIONAL DISTRICT.

Thomas T. Kinney.......................................Newark.
(Vacancy.)

VII. CONGRESSIONAL DISTRICT.

Lebbeus B. Ward.......................................Jersey City.
Samuel B. Dod..Hoboken.

VIII. CONGRESSIONAL DISTRICT.

Henry Aitken...Elizabeth.
(Vacancy.)

*Resigned December 20th, 1892.

GEOLOGICAL SURVEY STAFF.

STATE GEOLOGIST.

John C. Smock..Trenton.

GEOLOGIST IN CHARGE OF PLEISTOCENE GEOLOGY.

Rollin D. Salisbury..................................Chicago, Ill.

ASSISTANT GEOLOGIST.

C. W. Coman..Trenton.

CONSULTING ENGINEER AND TOPOGRAPHER.

C. C. Vermeule...New York City.

ASSISTANT-IN-CHARGE OF OFFICE.

Irving S. Upson..New Brunswick.

To His Excellency Leon Abbett, Governor of the State of New Jersey and ex-officio President of the Board of Managers of the Geological Survey of New Jersey:

SIR—I beg leave to present herewith the Annual Report of the Geological Survey for 1892.

Respectfully submitted,

JOHN C. SMOCK,

State Geologist.

TRENTON, N. J., December 20th, 1892.

REPORT.

The record of progress made in the geological survey of the State in the year 1892 is presented in this Annual Report of the State Geologist. The presentation of the work done in the several divisions or departments of the Survey is necessarily incomplete, as many details are incapable of proper classification in advance of thorough investigation of the subjects of study upon which it is engaged. There are gaps also for which data are still wanting in order to full and clear statement. In view of the constant accession of new material, and its proper assimilation, it is difficult to shut off the tide of accumulation and to summarize results and present complete or final reports in any of the several divisions of work. The annual reports, therefore, lack the fullness and comprehensive generalizations which characterize monographs or final reports, and are necessarily reports of progress.

The several departments of the work of the Survey form the basis of its organization and the reports of progress made in these various lines of investigation are incorporated in the annual report, as leading heads or parts thereof. They are to some extent separate and independent of one another, representative of the results of studies and surveys by these divisions into which the organization is arranged, although all have for their object the elucidation of the facts of geological structure and the physical geography of the State, and as an ultimate end, the information of the people in order to the highest development of the natural resources which surround every home in the State.

The report is divided into the following parts:

The administrative report, introductory to the reports of the several divisions, has as topics of discussion: Pleistocene or surface formations; Cretaceous and Tertiary formations; water-supply and water-power; artesian wells; sea-dikes of the Netherlands; reclamation of tide-marsh lands; drainage; natural parks and forest reservations; work of the United States Geological Survey in New Jersey; the Geological Survey exhibit for the Columbian Exposition; office work; Geological Survey rooms; publications; and staff of the Survey.

PLEISTOCENE OR SURFACE FORMATIONS.

The study of the surface formations of the State has been considered one of the important divisions of work of the Geological Survey. In the general summary of the work from 1864 to 1868, and published under the title of Geology of New Jersey, several chapters were devoted to the description of some of the more prominent features of the surface.* In the progress of the survey in succeeding years more detailed examinations were made and noted in the annual reports. The terminal moraine attracted attention by its marked topographic features and mixed constituent materials, and its limits were given in the report for 1877,† and again in the report for 1878.‡ A more comprehensive report on the surface geology was prepared in 1880 and published as a "report of progress."§ In that report the terminal moraine of the glacial drift was traced, the marks of the retreating ice-sheet in "moraines of recession" were noted, and the glacial drift south of the terminal moraine was referred to as "transported glacial drift."‖ The existence of an older and more southern drift in the central part of the State, and south of the terminal moraine, was referred to, and as probably glacial in origin.¶ The yellow gravels of the central and southern parts of the State were shown to be still older, and possibly of later Tertiary age.** In 1885 the same gravels were further studied by N. L. Britton and F. J. H. Merrill, and their results were given in the report for that year.††

The work of Prof. Salisbury was begun in 1891, and a preliminary report of his studies appeared in the last annual report.‡‡ This division of the survey has had a large share of the annual appropria-

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* Geology of New Jersey, Newark, 1868, pp. 168–170; 226–230, and 327-330.

† Ann. Rep. of the State Geologist for 1877, pp. 9-22.

‡ Ann. Rep. of the State Geologist for 1878, pp. 8-23.

§ Ann. Rep. of the State Geologist for 1880, pp. 14-97.

‖ Ann. Rep. of the State Geologist for 1880, p. 37 et seq., and pp. 76-87.

¶ Ann. Rep. of the State Geologist for 1880, p. 81.

** Ann. Rep. of the State Geologist for 1880, p. 87.

†† Ann. Rep. of the State Geologist for 1885, pp. 55-57.

‡‡ Ann. Rep. of the State Geologist for 1891, pp. 35-108.

tion, and its work has been pushed as vigorously as the means allotted to it would permit. One of the leading objects is a geological map of the surface formations. As they are found in all parts of the State and in places covering the older rock formations over large areas, the areal work is practically as extensive as the limits of the State. The base for the representation of the Pleistocene or surface formations is that of the topographic survey, and the maps of the atlas of the State are colored to show the various classes of deposits belonging to the Pleistocene period.

The progress made in the study and mapping of these deposits in 1892 is stated in Professor Salisbury's letter of transmittal (see page 35). The difficulties met with in the earlier stages of the work have been largely overcome, and methods for more rapid advances have been learned, so that in all probability the survey of the whole State can be made within the period of the present legislative appropriation, and a complete map of the surface formations be prepared and published at its close. The present time is opportune for making a geological map of this kind, after the topographic survey has given the configuration or shape of the surface in its detailed maps, and before culture has so far modified the character of the surface, obliterating the landmarks whereby some classes of these surface formations are recognized, that mapping would be impossible or extremely difficult. In the history of topographic surveys in our country the State has led, giving to its people the first complete topographic State map. It is, therefore, eminently fitting that this advance should be maintained and the geological map of its surface formations be the type which others shall study. The position of the State, so near the large city populations of the middle Atlantic coast and the centres of geological schools, will make some of the more characteristic features of the surface formations type areas in glacial geology. The educational element in the results of the work is suggestive of their use in the public schools and colleges in the State to a higher degree and greater extent, even, than that of the topographic maps, which have done so much for the local geography. The geological map of the State, which shall exhibit the till, moraines, kames, eskers, overwash plains, valley trains of gravel and sand, lacustrine deposits and other classes of drift due to the ice invasion of the State, will be a guide to these type-areas and localities of geological interest to glacialists and all persons who wish to know more of the history of so recent a geologic period.

This survey has added much to our knowledge of the glacial formations in its differentiation of so many new classes of deposits having their origin in the ice invasion. The kames, eskers, valley trains, overwash plains and berg till are discoveries made by it. They had not been recognized or described in the earlier work or before Prof. Salisbury began his studies of the Pleistocene formations. He has discussed the relations of these various deposits and traced their

history to the glacier sheet which covered so much of the State in the earliest ice epoch. The work of the ice has been graphically described in its on-coming and advance over the State to its most southern limits, in its temporary halting and re-advance, and in its final retreat, with all the changes produced in the underlying rock-floor and the deposits left by it in their diverse yet related phases. The phenomena of lake basins and diverted river channels have been considered. The arguments for the existence of Lake Passaic are demonstrative and suggestive. The change in the course of the Raritan river is another and unique example of changes due to the glacier sheet.

The careful study of these surface formations is expected to demonstrate the age of the Trenton gravels and their place in the sequence of events connected with the glacial epoch. The arguments for the antiquity of man based upon relics, ascribed to human agency, which have been found in the Delaware valley at and near Trenton, cannot be said to be decisive until the questions of the age and geologic history of these gravels have been settled. The importance of a careful study and the correct interpretation of the phenomena at this locality and their proper reference to geologic horizons is clear to all who are acquainted with the world-wide references which have been made to the Trenton gravels and the arguments therefrom in favor of glacial man. The archæological bearing of the work is, therefore, important and indicative of results of value.

This study of the Pleistocene or surface formations contributes to our knowledge in the explanation which it gives of many features of the landscape which seem strange, and of the confused variety of slopes and irregular assemblages of hills and valleys. The terminal moraine hills, the shore terraces of the old Lake Passaic, the eskers at Ramsey's, the overwash plains at Morris Plains and Plainfield, and the kame areas in the valley of the Hackensack are some of the more prominent features in the surface configurations of the State which are understood in the light thrown upon them by it.

The foreign materials on the surface—the erratics—are traced to their parent rock. The drift-covered slopes are interpreted and their history is read in the materials and forms which they disclose to critical study. A new and a later chapter is thus added to our knowledge of the past history of the surface under our feet.

The accurate survey of the surface affords a guide to the scenery and those features of the landscape which are characteristic, and in some cases give them particular value or fit them for special uses. The subject has been presented in a most attractive manner by Professor Geikie in his "Scenery of Scotland." In New Jersey the rock formations are the rocky skeleton, and the larger features of the surface are due to it; but over it there is thrown a mantle of loose materials which constitute the surface formations. The drift-covered northeastern Highlands as contrasted with the nearly driftless ranges of the same formations at the southwest are illustrative of the soften-

ing in the features produced by the glacial drift. But the exceptions are numerous and a detailed map is necessary to explain them. In the red-sandstone district the diversity due to the drift is equally great. On the trap-rock ridges the modification in the surface is very marked in many localities. Short Hills is a notable example of the utilization of a moraine for a town site. Madison, also, is on the moraine. The drift hills at Alpine and Closter, on the foot of the Palisade mountain, make beautiful sites for rural homes. In a word, much of the variety in the landscape and many of the beautiful sites for country seats and suburban settlements in the northeastern part of the State are owing to the diversified surface produced by accumulations of glacial drift and terraced forms of glacial materials. Diversity has taken the place of uniformity and simplicity in form through the moulding hand of the glacier and its ice-carried load of foreign materials.

The adaptations of the surface to particular uses, as forestry and its proper domain, also are indicated by this survey of the surface. The bowlder-strewn hillsides are as unfitted for clearing and tillage as the mountain slopes where ledges are everywhere prominent and the rock outcrop is a large part of the surface. Where the till is comparatively free from bowlders, the ground may be farmed with profit, but generally the till-covered mountain sides are adapted to forestry rather than agriculture. The kames, eskers and overwash plains, referred to in this report and mapped, are also less suited to profitable farming than to forestry. These classes of surface formations are unsuited for general farming, and they are the areas which should be devoted to forestry. And a State supervision of forests and far-sighted management would relegate some of the farm lands on these thin and bowlder-crowded soils to their natural crop of trees. It is not possible to particularize by localities. The general principle is clear that forestry should claim the larger part of these formations which are not adapted to profitable farming. A map of the surface becomes therefore the basis of a State map in a consideration of the forest lands of the State.

The importance of the careful study of the surface formations to a proper classification of the natural soils of the State and an accurate agricultural map was referred to in my last report. Soils have been classified generally in terms descriptive of their physical composition and texture. They have been referred to the underlying rock formations, as gneissic, limestone, slate, &c.—according to the nature of the rock.* Inasmuch as the rock outcrops are subordinate in extent to the great sheets of till and other drift concealing them, the consideration of the nature of the surface formation is important in the study of the soil, and the basis of a proper classification is in the surface

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*The soils of New Jersey were classified as gneissic, limestone, slate, shale, marly, &c., &c., by Prof. Cook, in the first report of the State Board of Agriculture.

geology. This classification is genetic, relating as it does to their origin and the changes produced by geologic agencies at work altering the nature of the surface. The conceptions of a scientific agriculture embrace the origin and successive changes of the surface. The till deposited under the glacier is generally a heavy and cold surface and wet. On the other hand, the sand and gravel ridges and hills which were left by the melting of the ice-sheet in the valleys, and known as kames and eskers, are noted for their porous and non-retentive characters and thin soils. In this way it is possible, by careful examination and study of details, to map the areas so marked by surface characteristics as to determine their agricultural values and their specific relation to the production of crops, and produce an agricultural map. The progress of modern scientific farming is to break down the limits of these natural groups and to make the whole surface productive, and it is successful wherever land is so valuable that however poor it may be naturally it can be so amended and enriched as to become fertile. The limit to this betterment is reached at a short distance from cheap transportation lines and good markets. The larger part of New Jersey is still beyond this limit and these natural provinces determine the character of its agriculture. The wheat-growing territory, the pasturage or dairy districts, the orchard, the Irish potato, the sweet potato and other staple crop areas are on the soils where these crops thrive, and they are within limits traceable on the maps of the surface formations which have resulted in the existing soils and subsoils. Therefore, the relation to agriculture is close and important in its suggestions of treatment and adaptations. The geological period in which these changes occurred, the limits of which are mapped in the survey of the formations of the surface, was the last and most recent—*Pleistocene*—the transition age, when the surface was being fashioned for man and for his support by its tillage. The characters of these surface-beds which go so far in determining their value as the basis of good or poor, fertile or barren soils were impressed upon them in that Pleistocene time or were largely modified by conditions then existing and belonging to it. The geological history shows what is the probable value of a surface formation as the basis of a soil for agricultural uses and is to some extent indicative of the kind of treatment and the nature of crop to which it is best adapted. To particularize: the granitic and gneissic-rock outcrops free from glacial drift, form a coarse-granular and well-drained soil and subsoil, sufficiently retentive for holding fertilizers, and therefore a good soil for general farming. The trap-rock soils are clayey and apt to be cold. This survey is, therefore, the key to the situation and gives not only the limits but also the reasons for the existence of these diversities in well-marked districts. It shows the range of crops and that distribution which is consistent with the capabilities of the soil in the various natural districts of the State, and also with the highest development of the resources and the least expenditure of force

Agricultural economy is thus related most intimately to the geology of the surface.

CRETACEOUS AND TERTIARY FORMATIONS.

The study of the Cretaceous and Tertiary formations of the State, which was begun by the co-operation of the United States Geological Survey with the State Survey in 1891, was continued during a part of the summer. Prof. William B. Clark, of Johns Hopkins University, Baltimore, is in charge of the work. His studies of the later geologic formations of the Atlantic coast, particularly in Maryland and Virginia, have given him a wide acquaintance with them, and have prepared the way for a more detailed study and the correlation of the New Jersey deposits and fossil forms with those of the Atlantic coast generally. The small appropriation allotted to him was insufficient to pay for a full season's work, and a part only of the area occupied by these formations was surveyed and mapped. In the historical sketch of this report the work done in their study is noted, but it is pertinent to refer here to the examinations of the late Professor Cook, in order to show the relations of that work to what is now being done under the direction of Professor Clark.

The preparation of the reports on greensand marls, published in 1868, in the Geology of New Jersey, covered surveys in the field which demonstrated the existence of the three marl beds and showed their relative position and their gentle southeast dip, as well as the unconformity of the overlying clays and sands which were assigned to the Miocene horizon. Many chemical analyses were made of the marls on account of their economic importance as fertilizers in the belt of country where they occur and their value in agriculture to adjacent parts of the State. The relative amounts of greensand in the marls of the several beds, their physical characters, and the chemical composition of the greensand or mineral glauconite were also subjects of investigation at that time. The increasing use of the marls suggested further chemical examinations, the results of which were published in the annual reports of the State Board of Agriculture and in those of the Geological Survey.*

These reports did not give specific information on the origin of the greensand, so unique and characteristic as it is of a part of the Cretaceous beds, nor of the varying conditions attending their deposition. The absence of this mineral in the clays and sands of the Raritan formation, or the plastic clay series, as it has been called, and its presence throughout the overlying and later clays, marls and sands of the marl belt, are facts indicative of altered conditions and afford valuable generalizations. Professor Clark has discussed at some length the question of origin of the greensand, and the relations of

* First Annual Report State Board of Agriculture and Annual Report Geological Survey for years 1872, *et seq.*

the several beds to one another. This part of his report is exceedingly interesting and suggestive of further investigation in this field. The information is highly educational, if not so utilitarian as that of older reports on our greensand marls. And the subject is one which will no doubt find many readers among the intelligent farmers who have used so much of this valuable natural fertilizer and have profited so greatly by a liberal use of it. The relation of the red-sand bed to the marl beds in nature of material as well as in its forms of life, the extension of the upper marl bed so as to take in the underlying yellow sand, and the separation of this part of it from the higher blue marl, formerly included in the upper marl bed, are features of this report which deserve attention. The reference of the fossil forms of life to the particular beds, so far as it is possible, is also interesting, and is suggestive of further work in collecting more carefully in this field than has been done.

The geological map which illustrates this report, represents the work done in the field in determining the boundaries of the several beds within the area covered by two sheets of the map of the United States by the United States Geological Survey. The base differs slightly in scale from that of the New Jersey maps, but is from the same topographic survey. The woods are omitted, as their representation tends to confusion with the colors used for the various beds. This map is the first of a new series on a large scale, and it shows most interesting geologic outcrops and a rich agricultural district. The practical value of a geological map of this kind is apparent to all who seek a more thorough knowledge of the geologic structure of the country, the location and extent of the beds of clay marl and marl, and their intimate relation to the soils and their agricultural development, and to the topographic features in all their range of economic importance. The clay marls are the basis of much of the brick-making industry of this part of the State as well as the clays of the Raritan formation; the marl outcrops constitute the naturally fertile areas and the red sand bed forms the beautiful range of Mount Pleasant hills and Navesink highlands, as also some of the more productive soils for fruits and some root crops. The use of the marl has declined largely since the introduction and more general use of the commercial fertilizers, but it ought not to be forgotten that heavy dressings of marl have enriched permanently many farms, and have contributed to their greater productiveness even after its disuse. The map has, therefore, a value to the agricultural student and to the farmer because of its accurate delineation of the marl outcrop and the outlines of the marl belt.

The report gives little space to the discussion of the Raritan formations of plastic clays, sands and associated beds, and does not materially contribute to our knowledge of the same. The reference to the possible extension of the Cretaceons beds over the red sandstone of the Jura-Trias is suggestive of the need of much more study

before it may be accepted as explanatory of some observed facts. A report on the clays of the State, in course of preparation, will afford a proper place for the discussion of this question.

The study of the greensand marls, and particularly the clay marls, and their relations to the underlying formations is expected to show a possible subdivision of this member of the series. The determination of the horizon of the Shark river marl and its relation to the lower marl beds, and the further detailed surveys in the overlying Neocene or Miocene beds, are interesting problems for work in the future. It is hoped that our appropriations may admit of so large an allotment that the co-operation of the United States Geological Survey may be continued, and that the geological mapping may be extended southwest over the whole greensand marl belt.

WATER-SUPPLY AND WATER-POWER.

Mr. C. C. Vermeule, topographer and consulting engineer on the staff of the Geological Survey, has had charge of this division of the work, which has for its investigation the study of the stream-flows and the survey and mapping of the natural water-sheds or hydrographic basins of the State. Two annual reports of the progress made have been published. The third report, and that for the year 1892, appears as Part III. of this report. The delay in completing the work has given more time for the observation of stream-flows, and these longer periods of measurement have a much greater value than that of one year could have. There are at present four observers only who report on stream-flows. The others have discontinued work and their records are ended. All available existing data on the subject have been gathered from engineers and others in the State. The reduction of these observations has required some additional surveys of lakes and stream channels. All of this material will be valuable in the study of the capacity of streams and the water-supply available from them. The question is of great importance, particularly to the residents of our larger towns and cities. It has been referred to in the annual reports of this Survey every year since 1876, and the information in them has been of service in securing better supplies for some of the cities. It is still a vital question and deserving of the attention of all interested in the health of the people. For the more intelligent discussion and consideration of the various sources of available supply, the official estimates of the capacity of the water-sheds should be made public in these reports. A part of this information is given in this report. A map of the State is added to show the location and extent of the water-sheds in the north-eastern part of the State which are now in use and those which are available for additional supplies. The elevations at the outlets are also given. The map of all of the water-sheds in the State and their

areas was given in the Annual Report for 1890. This map is therefore supplementary to that one. It may be noted that the available areas are all, in part or wholly, in the Highlands, except that of Saddle river.

The Highlands are most valuable gathering territory for water-supply on account of their rock formations, the large area in forest, the sparseness of the population and the excellence of the water. There are available sites for pumping-stations on the lower red-sandstone hills and valleys and nearer some of the cities and towns of that part of the State, and some of them are utilized, but the superior fitness of the Highlands is unquestioned, and therefore attention is directed again to that district. The map shows how large a part of it is yet unoccupied and desirable as sources of abundant supplies of wholesome water. The rocky surface of these mountain ranges has retarded the clearing of the forests and saved them in comparative nearness to the densely-populated valleys on their southeastern border. Geologic structure and conditions of surface due to geologic agencies give us the explanation for this natural provision so remarkable in its congruous fitness and so valuable in the development of the State. So much has been written on this subject that it seems to be unnecessary to refer to it again in these annual reports. The subject is, however, so important in its relations to the health of communities, as well as so conducive to the highest enjoyment and utilization of the natural resources of the country, that attention is again asked to the Highlands and the water-sheds which are available for large supplies of excellent water and at heights of 190 to 280 feet above tide-level. Quantity alone should not control in the decision of the question of source any more than cost, and both should be subordinated to quality, especially in view of the economy of health and life in the use of pure water, as compared with the losses incident to disease and death which are traceable directly to the use of water of inferior quality or of polluted nature. The time is coming when the æsthetic considerations involved in the nature of the water used by a people will have more force than they have now, and filthy water repugnant to the taste will be replaced by supplies drawn from more attractive sources. All of these arguments point to the Highlands as the natural gathering ground for the drinking-water of the city populations in the northeastern part of the State.

The volume on water-supply and water-power is in course of preparation and is to be published as soon as it is ready. It is hoped that it can go to press sometime in 1893. The contemplated volume will be a hand-book of reference on this subject, giving information on the sources of water-supply and the quality of waters, and on the available water-powers and the sites now in use and capable of development. It is to be uniform in style with the volumes already published and known as the Final Report of the Survey.

The water-sheds of the streams in the central and southern parts of

the State are not shown on the map of the State which accompanies the report and illustrates the paper of Mr. Vermeule. The equable flow of many of these streams, their capacity and the excellence of the water generally have been mentioned in the reports for 1890 and 1891. The complete utilization of the water of a limited area for local supplies has not been attempted in New Jersey. This system of saving all of the flow from a given area which is guarded against any possible pollution was seen in use last summer at The Hague, the capital of the Netherlands. The cities of Amsterdam and Leyden also use it. The gathering grounds are on the coastal dunes not far from these cities. The Hague utilizes a section of the dune range about three miles long for its supply. The area is under the control of the municipal authority and is therefore guarded against any possible source of contamination of its water. The whole surface is underlain by a network of drains, and the water falling on the surface and sinking into the sands finds its way into the drains. The drainage of the hills of the area into the lower ground is largely from a considerable depth, so that the water is not all from a superficial stratum of the dunes. There are a few comparatively small open water areas or lakelets which are practically small reservoirs and they constitute a part of the system. The drains are so arranged as to carry all of the water to the reservoirs, whence it is pumped into the main distributing reservoir. The water is excellent in quality and absolutely safe against pollution. The range of dunes on our Atlantic coast, known as the beaches, affords small areas for the use of this system or source of water-supply. Wherever the land can be had cheaply and can be controlled for the purpose it is possible to get good water for limited local use, and there are small settlements, and even towns, so situated that water from the adjacent unoccupied beach might be used. Assuming the available rainfall which can be collected to be twelve inches in depth for a year, an acre is capable of yielding about 300,000 gallons, or nearly 1,000 gallons daily. At the same rate a square mile can give a supply of 572,844 gallons a day, enough for a town of 5,000 inhabitants. When this use of the surface is coupled with the growth of forest or the protection of the sand-hills against the moving action of the wind on the same area there is an indirect advantage gained. For some localities this source seems to be one worthy of consideration by authorities or owners in search of a better supply than artesian wells can afford, and where water from the mainland cannot be had without large and expensive constructions.

ARTESIAN WELLS.

Artesian or deep-bored wells continue to be the source of supply of good water in many localities, and many wells are bored each succeeding year. The success in getting water has stimulated the exten-

sion of the system until the whole southeastern coast is supplied with water obtained from this source. There are new wells outside of the coastal belt in the southern interior and along the lower Delaware valley, and in the central and northeastern parts of the State, which are as remarkable for their abundant flow as those in the coastal belt. The low cost of water from artesian wells is in their favor, as compared with that of aqueducts and reservoirs. The subject is attracting the attention of many small communities and establishments which consume a large volume of water at considerable cost for water tax; and many inquiries are addressed to this office for information on the nature of the strata, the possible existence of water-bearing beds, quality of water obtainable, volume of flow which may be expected, and other data pertinent to the question of an artesian supply. The general interest in the subject, and the practical value of data from wells, has made it imperative to continue the work of gathering all available facts and thus preserving as complete a record as possible of the artesian wells in the State. This work, begun several years ago by Lewis Woolman, of Philadelphia, has been continued throughout the year. He has given to it such attention as was consistent with other and business engagements, and the work has been largely a labor of love. His careful and painstaking efforts, his enthusiastic search for any new undertakings and his diligent comparative study of the facts obtained are evident in his reports. The record of the new wells in the southern part of the State is full. A few localities in the northeastern part are not included in the paper. His report on artesian wells makes Part IV. of this annual report.

THE SEA-DIKES OF THE NETHERLANDS.

By permission of the Board of Managers of the Geological Survey, I was enabled to be absent a part of the summer and autumn and to visit Europe, in order to study the Dutch system of sea-dikes. An official letter from Governor Leon Abbett to the Waterstaat, or bureau of the Dutch government in charge of these protective defenses of the kingdom, secured the proper introduction and the most hearty cooperation on the part of the authorities having control of them. An engineer of the Waterstaat was detailed to accompany me to the more important points and to introduce me to the local engineers and superintendents. This officer was interpreter as well as guide and rendered valuable assistance in translating notes and giving access to official maps and surveys. The local engineers at points visited were also directed to do whatever would facilitate my inquiries. It is pleasant here to mention the names of the Honorable Minister of the Waterstaat, C. Lelij, who gave the necessary directions to his subordinates upon the receipt of Governor Abbett's letter; the Hon. S. R. Thayer, United States Minister to the Netherlands; Mr. G. v. Diesen, resi-

dent engineer of the Waterstaat at The Hague; Mr. F. Doffegnies, also engineer of the Waterstaat, who was my guide in visiting the West Kappelle, Flushing and Petten sea-dikes; Mr. R. O. van Manen, Chief Engineer of the Waterstaat, resident at Haarlem; Mr. J. P. Wytenhorst, engineer at Flushing, and Mr. A. H. Straater, superintendent at Petten. Their kind attention and courtesy deserve this public recognition. The data on sea-dikes given in this report are the results, in part, of their painstaking attention, without which little accurate information could have been gained in the time at my command.

Three points, Helder, Petten and West Kappelle, were selected for examination, and they were visited. The range of dunes is wanting at these places and the gaps are filled by formidable sea-dikes. At the Helder—the entrance to the Zuider Zee—the massive works make a part of the military defenses of the country, and fortification and dike are continuous and one. At Petten, in the province of North Holland, there has been a break in the range of sand hills and a strong dike has been built to keep out the sea from the land behind it, which is several feet below the ocean level. The works are under the control of the Waterstaat and a government engineer resides there, whose duty it is to inspect the work and to report on its condition to the general office at The Hague. The works at West Kappelle, in the island of Walcheren and in South Holland are of a like kind and are also under the control of the Waterstaat or Water Bureau. The dikes at the harbor of Flushing also were visited. They serve to guard against the waters of the Scheldt, here a wide estuary, and to make, as it were, a land-locked harbor, having deep water and affording room for vessels of large size and draught.

Many other localities in the provinces of North and South Holland and of Utrecht were visited, and dikes along rivers and canals, dikes used as promenades and drives in cities, and interior or subsidiary dikes, as well as the great sea-dikes above mentioned, were seen, and notes of their construction and maintenance were made.

The western and northwestern or coastal belt of the Netherlands is nearly all below the level of high tide, and through the removal of the superficial peat and the subsidence due to drainage and cultivation, much of this territory has settled to a lower plane, so that there are large areas which are several feet below even the level of low tide. The surveys and maps of the country show that the range is down to twenty feet below the Amsterdam datum plane or A. P.* of the Dutch engineers. The preservation to agriculture of this exceedingly fertile and productive part of the kingdom is in the maintenance of the system of dikes, which are the results of centuries of work and at the cost of many millions of guilders. The control of this network of canals and dikes and the protection of the land, on account of the

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* A. P.: Amsterdamsch Peil—Amsterdam pile or datum.

many private interests involved and the extent of the territory, is of necessity lodged in a government department. The management is thorough, efficient and economical of expenditures. The want of land for the supply of food to the densely-populated country and the large cities on these low-lying and impoldered districts and the cheapness of labor have made it possible to do what elsewhere and under other conditions cannot be done. The dikes were a necessity. As has been said by De Amicis in his "Holland and Its People:" "Holland is a conquest made by man over the sea; it is an artificial country; the Hollanders have made it; it exists because the Hollanders preserve it; it will vanish whenever the Hollanders shall abandon it." *

The application of this system of sea-dikes to our coast is perhaps not practicable, because there is not the necessity for them as a means of defense against the sea, except to arrest the eroding action of the waters at a few points. Some modification of the dike, and this combined with a system of jetties, may answer our needs. The great size and the enormous expense of construction preclude the possibility of copying the example the Dutch show us in their great sea-dikes.

The importance of some better means of protection than that afforded by the jetties and the wooden bulkheads which are in use on our coast, has suggested the presentation in this report of some notes on the sea-dikes of Holland and also on what may be done by dikes and jetties to protect our shore front at more exposed points. These notes are on pages 315–329 of this report.

RECLAMATION OF TIDE-MARSH LANDS.

This subject has been referred to in previous reports of the Geological Survey, and at length in the annual reports for the years 1866, 1869 and 1870.† During a visit to the Netherlands last summer, made by permission of the Board of Managers of the Survey, for the purpose of studying the means employed to protect the coast against the encroachments of the sea, I had opportunity to see a large part of the country which has been reclaimed and has been put under a high state of cultivation. The success has become a subject of world-wide fame and the example of the Dutch pointed out as a great lesson to other lands and peoples. The work of centuries has added tract to tract, or *polder* to *polder*, as these embanked and drained lands are termed, and lakes, tidal waterways and broad estuaries have been made into arable land and nearly all of the rivers have been shut in between dikes and controlled so that they appear more like great

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* "Holland and Its People," p. 2, New York, 1881.

† Ann. Rep. of the State Geologist for the year 1869, Trenton, 1870, pp. 23-41, and Ann. Rep. of the State Geologist for the year 1870, New Brunswick, 1871, pp. 18–63.

canals than natural channels through which the waters draining large interior territories find their way to the sea. The fertile soil of much of this polder land and the rich pastures and gardens were evidence of what patient and painstaking labor and continued, thorough work in the care of the soil had done in that country. The land thus reclaimed is not all equally productive. Where sand flats were, or old belts of sand hills or dunes, the surface is sandy and is not as fertile as that of the sea-clay bottoms or the clays of the old river channels. In general, the clay lands have made the famous meadows for pasturage; the sandy tracts and areas, the market-garden and notably, the flower-bulb grounds. Naturally, our tide-marsh lands are as good as those of the Netherlands which have been drained, and the more clayey parts are adapted to pasturage or tillage when reclaimed. The nearness of much of this tidal plain to the great cities of the adjacent States as well as those of the State, the accessibility to these markets by railway and water-way lines of carriage for freight, and the practicability of their reclamation seem to be strong arguments for draining and improving them. And attention is asked again to the subject as of public interest and within the scope of profitable private undertaking. There are in the State 296,500 acres of these tide-marsh lands, nearly all of which is without forest and much of it is capable of drainage. This area is nearly one-eighth of that of the cleared upland, in farms, in the State. At present it yields crops of salt grass and sedge which have some value and are salable, but the income is probably not one-tenth that of rich upland in the same locality. The relative importance of *salt meadows* to upland has declined within the last half century and such land is neglected for agricultural uses. The addition of this area to the cleared and productive farm lands of the State would amount to more than ten per cent. of additional farm lands and would yield an increase of twenty or more per cent. of farm products. The development of the natural resources of the State should include the marshes as a leading element in the production of wealth, and the attention of capitalists and of the citizens of the State should be directed to them by the Survey.

The work of reclaiming the marshes from the tidal waters along the Delaware river and Delaware bay was begun as early as 1700 in the vicinity of Salem. There are many embanked meadows along the river and some of its tributaries, and some of the tracts inclosed by a single line of banks or dikes are large. One at Finn's Point, in Salem county, contains 1,200 acres, and the bank is broad enough on top for a roadway and is ten feet high. In Elsinborough township, half of the whole area is embanked-meadow land. Large tracts were formerly banked along the Cohansey creek and the Maurice river, but much of it has been abandoned to the tide again. No attempt has been made in this part of the State to drain the water below low-tide level, and there are sluice-gates only for letting off the

waters at low tide. So far as is known, no artificial means of draining off the water has been attempted anywhere in the State from such lands devoted to crops or pasture.

Very little work in draining tide marshes has been done on the eastern side of the State, except on the Newark meadows east of Newark, where a company was organized and began the work of reclaiming a tract of about 6,000 acres lying between the Passaic and the Hackensack rivers, and on the line of the railways which there cross the meadows. The banks were built with an iron-plate core, for security against the ravages of muskrats, and for greater strength. The water was shut out down to the level of low tide and the meadows became comparatively dry, and upland plants and vegetation appeared. This work was done about twenty-four years ago, but the project to drain lands there for farming was a failure. According to the survey, about 4,000 acres is embanked and 1,550 acres of it is improved.*

The total area of tide-marsh land embanked in the State was, in 1888, 34,304 acres.† Of this area, about 30,000 acres were along the Delaware bay and the streams flowing into it, and in the southern part of the State.

Surveys of the meadows at the head of Newark bay and along the Hackensack and of those in Salem county were made in 1869, and the maps of these surveys were printed in the annual report of that year. The depth of the mud was sounded on lines crossing the marshes, and the nature of the material of the surface was noted. The maps show the parts which are clay, clay and peat mixed, and peat or vegetable matter only; also, the depth of the mud, or mud and peat.‡

The later topographic survey of the State has given more accurately the boundaries of the tide-marsh lands in the State, and they have been mapped in detail, as shown on the sheets of the atlas of the State. For the location and extent of the tracts of these lands, reference may be had to the topographic maps.

Agricultural depression during the last decade of years has perhaps been the leading cause in the neglect of the embanked meadows and the non-extension of drainage works generally. The farmer has had too much upland, and the salt meadows have received little attention. The increase in the arable lands of the State has been comparatively small since 1880. Speculative projects are also answerable for this neglect, through their failures to yield the incomes anticipated, and it is unfortunate that there should have ever been any organized attempts to do more than drain land valuable for ordinary agricultural uses, and, at average farm-land prices, capable of yielding a fair

* Final Report of the State Geologist, Vol. I., p. 101, Trenton, 1888.

† Report cited, p. 94.

‡ Copies of the Annual Report of 1869 are still to be had on application at the office of the State Geologist.

rate of interest. And at the present time there is no prospect of extraordinarily large returns to be had from any drainage or reclamation projects in the State, except on some small and favorably-located tracts, where the land has a value for other uses than for cropping. It ought to be added here that the probable success of any reclamation project is dependent largely upon the kind of crops to be raised. For general farming, and particularly for the staples, corn, wheat, grass and potatoes, it is doubtful if any capitalists can be found to put money in embanking even well-situated tracts to produce these crops. The more profitable crops which are raised near large city markets and a more intensive agricultural practice are demanded on lands reclaimed at costs which make their valuation greater than that of the neighboring upland. It is important that the experiments which may be made shall be at points and on tracts of good quality of soil, where the cost of banking can be reduced to a minimum and the tillage may give early results. It is believed that the outlay which is put in lands of this kind and at favorable points need not exceed very much the capital which productive upland requires for its purchase, and that such investments may yield a fair rate of interest. Looking to the ultimate development of all of our natural resources and the removal of the unsightly and malaria-breeding wastes, which are traversed by great railway lines in crossing the State, the need of some carefully-planned and judiciously-executed drainage projects on our tidal-meadow lands is of great importance and is much to be desired. For these reasons the subject has been referred to at some length in this report of the Survey. It is hoped that some examinations of drainage works in the State, and some surveys of the tide meadows and their adaptation to farm use can be given in the report next year. A paper on the polder lands of Holland and notes on the location and extent of our tide-marsh lands are to be found in this report on pages 331–353.

DRAINAGE.

The drainage of wet meadows and lands subject to overflow from floods in streams has had much attention given to it by the Geological Survey. Surveys have been made of several of the larger tracts of these wet lands and the location and area of all of them have been included in the general topographic survey of the State. And the maps of the topographic survey show the surface configuration and the lines of possible outflow or drainage of the waters which may cover them. Their relations to the general hydrographic system of the State as well as to the political divisions and the lines of transportation are also indicated upon these maps. In addition to the general State surveys, lines of level have been run through large tracts of wet lands and the fall of existing waterways or drainage channels and of

improved routes for greater fall have been ascertained. The nature and depth of the mud and peat also have been in some cases examined. The subject has attracted public attention and enlisted enterprise, and drainage methods have been undertaken and carried to successful completion. The results have been reported upon with much of detail in the annual reports of the Geological Survey. Ever since the publication of the Geology of New Jersey, in 1868, the drainage of the wet lands has had more or less reference to it in these reports. The subject is of perennial interest and no apology is necessary in introducing it again. In fact, the superior value of these drained lands for production of large crops, their easy tillage, the additional acreage of arable land and increment of public wealth, as well as the removal of unsightly waste lands and possible breeding-places of malarial disorders, are cogent reasons for keeping the subject constantly before the people. The work of the Survey, now in progress, in studying the nature of the surface deposits and in mapping the various formations which make this surface, has as one of its practical results, the reclamation of these lands. After the field survey of another season it is proposed to refer to them in some detail and more particularly in their origin and history.

The success of the Great Meadows drainage scheme in Warren county has been noted in the annual reports of the Survey.* Reference to the need of some common superintendence for keeping the channel clear and facilitating the discharge of the waters was made in the report for 1891. The control by the State, as in Holland, may not be practicable here, but the efficiency of the working of a governmental supervision and inspection commends the Dutch system or some modification to suit our conditions and modes of thought about the public control of such matters. It would seem as if there should continue in force some commission of drainage works or joint supervision by a representative body from the several land-holders. The interest of the land-owners in any drainage scheme and in its continued success should be the basis for any provisions made for continued supervision, and be in harmony with our common views of republican form of government. The representatives of the people of the locality, that is, the owners in question, are entitled to authority. Some amendment of the general drainage laws of the State is wanted to give authority to the representatives of the associated land-owners who may wish to have the benefits of a drainage project continued after the work has been done and the commission has ceased from its authority. The Pequest drainage needs it, and the delay in clearing obstructions, which may increase in the future, is threatening the permanence of the improvement. It is not necessary to refer to failures in the case of smaller experiments or projects for drainage, to enforce the argument for continued watchfulness on the part of some

* Ann Rep. of the State Geologist for the year 1884, pp. 112–119.

authorized representative of the owners in the case of the Great Meadows tract or other tracts which may hereafter be improved. Abandonment means loss of property and discouragement to others contemplating such improvements. The perseverance of the Dutch in holding what they have and in reclaiming from the sea the losses of the fourteenth and thirteenth centuries are lessons which may be stimulating and instructive in this holding on to lands improved at great cost, yet subject to reversion to their original condition if not cared for by constant attention and labor in maintaining the drainage improvements. These general statements are made to suggest the need of care and watchfulness on the part of the owners of the Great Meadows tract in order to its continued prosperity. The details are left where they rightly belong—to those most deeply interested in the property. It may be added that in the case of failure on the part of the land-owners to agree on any plan for the maintenance of the improvements, application may be made to the Geological Survey, and a new Commission be appointed to make such surveys and do so much work as may be necessary to drain the tract. By the terms of the law, five owners of separate lots of land included in such wet tract* may apply to the Geological Survey and ask for its drainage, and the Survey is thereby authorized and empowered to make surveys and plans for drainage. The report and plans are submitted to the Supreme Court, by whom the Commission is appointed to do the work of draining and raise the necessary moneys, to be assessed upon the lands improved.

Passaic river drainage.—The work at Little Falls, on the Passaic, has been carried forward nearly to its completion under the general supervision of George W. Howell, one of the Commissioners. The falls have been obliterated, and a channel eighty feet wide has been excavated through the rock and rock debris from the mill of the Beattie Manufacturing Company to the pool below the falls site. A channel twenty-five feet wide and sixteen feet deep has been cut through the rock from this larger channel to the site of the gates at the north end of the dam. The work has been done under contract by the Morris & Cummings Dredging Company, of New York. There is yet to be cut a channel through the reef of rock above the dam and through the bar of earth and loose stone at Two Bridges, in order to provide an adequate waterway from the upper level through these several obstructions and afford room for the delivery of the waters in time of flood from the meadows above Little Falls. The gates are to be put in by the Beattie Manufacturing Company as soon as the question of relative efficiency of the two forms proposed can be settled. The original plan of the Geological Survey required that the waterway be twenty-five feet wide and sixteen feet deep. Instead of

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*This act does not extend to lands flowed by tide. See Ann. Rep. of the State Geologist for 1888, pp. 49 60.

the ordinary vertical gates, having this size of discharge, three cylindrical or tubular gates, each nine feet in diameter, have been proposed as equivalent in delivery and less expensive in construction than the vertical form. They are not common and not so well known, and hence the change proposed has been regarded as experimental, if not at variance with the details of the plan of drainage on which the Commission is at work. The question is most important, and demands a careful consideration of all the facts of stream-flow and delivery of proposed channels as well as that of the various forms of gates. An examination of the flow of the river, and a new determination of channel capacities and the delivery rate in time of flood are wanted as data in settling the question of size of gates as well as capacity of their delivery. The efficiency at all seasons of the year and in case of obstructions also is to be considered.

The large cost of this Passaic drainage, the large number of land-owners in the valley, who are to pay the cost by assessments made upon their holdings of flowed lands, and the public importance of their successful reclamation and improvement make it imperative that no doubtful or inefficient steps be taken. The failures of the earlier schemes for the drainage of these Passaic valley lands also suggest careful consideration to avoid any possible mistake. It is hoped that another annual report may chronicle the completion of the work on channels and the setting of the gates, so that the obstructions to the delivery of flood-flows shall not be of such nature as to interfere seriously with raising and harvesting crops from the meadow lands along the Passaic.

The drainage works at Little Falls do not and cannot afford any relief to the wet lands along the river above Chatham. Their improvement is in part conditioned by obstructions near that place and their possible removal. They are not as extensive as those below, nor are they subject to so destructive floods. The Great swamp and the Dead river lands are unsightly, and their drainage would be an improvement in a country where property value is increased by its attractiveness and healthfulness. Water-power sites and water-power mills and factories are not so essential to the general public as conditions favoring health, and not as valuable as country for suburban residential purposes. And the State is interested in the development of its highest resources, values for residential purposes at some points and water-power developments at other and properly-located points where they are not subordinate in importance to more valuable interests.

It might be noted in this place that the drainage in the Passaic river is of great interest geologically, and its history is one of much variety. The existence of an old lake basin is referred to by Prof. Salisbury in this report (see pages 126–144.). Could this lake have continued, *i. e.* could the dam at Little Falls have been high enough to shut it in within its shore line as now traceable, the value of the

adjacent lands would have been perhaps greater than that of the highly-improved farm lands of the whole valley.

There are other large tracts of wet lands in the State capable of improvement by drainage of the surplus waters in times of flood. The Drowned Lands in Sussex county and extending along the Wallkill into Orange county, New York, is the largest of them. The Paulinskill meadows, near Newton, in the same county, is another tract of considerable extent. There are others also of importance and value, although not as extensive as these named.

The Drowned Lands is a comparatively narrow belt of flowed meadow land bordering the Wallkill, from near Hamburgh to the line of the N. Y. and L. E. R. R., near Denton. A branch runs up the valley of the Pochuck creek to Vernon. Several attempts have been made to drain the tract, but the improvement has been over a part only. The cutting of a new channel at Denton did much good in increasing the rate of discharge of the flood-waters. Surveys of the stream made by the Geological Survey show that the fall is very slight from the head of the tract to the State line.* An improvement is possible by dredging the channel and clearing it of obstructions, so as to promote a more rapid descent of the waters. Some of the bends might be cut off. The soil of this tract is nearly everywhere in it of a rich, black, vegetable mould, which is capable, when sufficiently underdrained, to produce valuable crops. Some of it is now meadow, where the pasture is rich and well suited for dairy farming. The aggregate value of the whole, if properly drained leads to the suggestion of considering the practicability of drainage. And in view of the value of the pasturage on the polder lands of Holland to the dairy interest, it seems as if the improvement of this tract should be somewhat as there made. The deepening and widening of the main channel, that is, of the Wallkill, is necessary in order to enlarge the capacity of its delivery. The digging of new canals or waterways, one main on either side, to catch the tributaries from the adjacent hill-country, would add greatly to the relief of the main stream. Intermediate and smaller canals and ditches should be dug to lower the water and also to serve instead of fences or hedges for field divisions. By means of some system of this kind it is believed that the whole tract might be valuable for pasturage, if not largely for cropping, as the best of the Dutch polders. And this improved meadow land would be more productive than the adjacent hill farms. At present ruling prices for farm land in Sussex and Orange counties, the cost of improving in this way would perhaps be so much as to be impracticable. But in view of the greater productiveness per acre when thus improved, the case does not appear hopeless. The example of the Chester meadows, near Chester, in Orange county, is suggestive of what may be done possibly on a part of the tract and of the large

* See Annual Report of State Geologist for 1871.

value of land of that kind. A difficulty appears in the fact that the tract lies in two States, necessitating some joint measures for drainage, and under legislation in both States which may enable co-operative work to be done by a Commission in charge.*

In these days of more intensive farming and wider competition these alluvial lands of the State deserve attention. They may be compared to some of the more valuable irrigation-farm lands, since they may be made to be practically irrigable in some cases, and in all they are more easily tilled than the older uplands, and to that extent more valuable. The alluvial lands of Europe are its food-producing territory, and the wet lands of New Jersey are comparatively as important as elements in our agricultural development. They ought to be in a high state of cultivation and much of the mountainous land as well as the more uneven and stony hills and valleys, now skimmed over by a slovenly and almost wasteful kind of farming, should be restored to forestry and to valuable gathering territory for large supplies of water for our cities.

NATURAL PARKS AND FOREST RESERVATIONS.

The subject of natural parks and reservations in the Highlands was noticed in the last annual report. The importance of easily-accessible retreats for the masses of our city population, as well as for those who are able to own places in the country or to have country homes, is such as to justify a repeated reference to the subject. The study of the physical features of the State which it has been the duty of the Survey to make, and particularly the more recent detailed survey of the surface formations, points to the utilization of those features which make certain localities and districts adapted to this use of them. The development of the resources in beautiful natural scenery and in health-giving resorts for the people of our crowded cities, is one of the eminently practical benefits of the studies and surveys which have been made of the surface. The beauty of the scenery and the healthfulness of localities are as closely related to the geology as the occurrence of ores and beds of natural products of economic value, or the soil in its endless variation. The explanation of much in all of them is alike to be found in geologic history. Many illustrations might be given so far as scenery of certain types and forms of beauty is related to the geology. That the healthfulness is as intimate in its relationship is not so easily shown. It is hoped that future reports on the geology of the surface may do much to point out in detail, and by the help of maps, exhibit at a glance localities and districts of characteristic topography and of forest covering and natural drainage which

*The Topographic Map, Sheet No. 4, of the Atlas of New Jersey, shows location and extent of the drowned lands and the streams to outlet at Denton, New York.

make them of specific value as health resorts, or as sites for natural parks and reservations for game preserves. In some of them there are remarkable natural features, which should be preserved by means of some associated or public supervision. The Highlands have been referred to repeatedly on account of their beautiful lakes, excellent water and surface adapted to the touches of landscape art. The trap-rock ranges of hills—the Palisades, Watchung mountains, Sourland mountain, Round Valley or Cushetunk mountain, and other lesser ridges, are prominent in the cultivated-plain country of the Triassic red sandstone, and afford sites of commanding and beautiful views. Many localities are well known and are much frequented. There is room for a much larger population on these hills and lower mountains. Of the more quiet beauty of the valleys it is not possible to do more now than to note that the explorer in the northeast and central parts of the State may discover what may suit him, and near railway lines of travel, so as to be easily accessible from the cities of the metropolitan district. Further away there is much of beautiful, quiet scenery in the Highlands valleys and in the Kittatinny valley.

The more specific purpose of this reference to the subject is, however, to call attention to the large and available tracts in the Highlands which are so well fitted to become natural parks for the use of the masses of our people who need the resort to the country and yet cannot afford to have country homes. Nearly all of the more attractive places and all of the larger lakes in the Highlands are less than thirty miles from Newark and Paterson and the adjacent towns, and a radius of forty miles from the cities of that part of the State would sweep within its range all of them and the greater part of the Highlands. One of sixty miles would take in nearly the whole of the northern part of State. It is the comparative nearness of so large a territory filled with wild-wood scenery and still in forest, and with so many lakes and lakelets within easy reach by railway, which is the attractive feature of this country, and more remarkable as we note the deforesting march of improvement over districts more suited to the demands of cropping or where the capacious maws of furnaces and mines, or the market for lumber have consumed the woods. It is not a region scarred by fires, as are some of the more remote and more pine-covered mountains of northeastern Pennsylvania or of the southern part of our own State. And it is naturally suited to the production of luxuriant tree-growth, excepting on the rocky mountain crests, and ridges, where the soil is necessarily scanty and not of a depth to make a heavy growth of wood. The preservation of the more beautiful and attractive parts of this region for use as large natural parks by our cities and as gathering territory for their supply of wholesome water, is a subject deserving of public attention before it be too late to secure them.

The action of the Massachusetts Legislature in creating, by enactment, a Metropolitan Park Commission, which shall consider the

advisability of providing open spaces in the vicinity of the towns and cities near Boston, is suggestive of what may be done at the proper time in New Jersey, and particularly in the thickly-populated north-eastern part of the State.* Inasmuch as the cities of Newark, Jersey City, Paterson and the adjacent towns get their drinking-water from the Highlands, they are interested in maintaining it in a forested condition. The question of some control over it for the proper utilization of its waters and its attractive scenic features, deserves attention.

WORK OF THE UNITED STATES GEOLOGICAL SURVEY IN NEW JERSEY.

The field work in the Highlands, in studying and mapping the crystalline rocks, begun and carried forward throughout the season of 1891, was resumed in the spring and was in progress until the middle of July, when it was suspended on account of want of funds for its further continuance. Dr. J. E. Wolff, of Cambridge, Massachusetts, was in charge of it. The preliminary work of studying and classifying the various rocks which make up the mass of the Highlands has been done, and the mapping, in detail, of their areas of outcrop has been begun and two sheets of the United States Survey have been completed. The study of geologic structure has revealed some facts which promise to have an important practical bearing on the occurrence of the magnetic iron ores in these formations. The results of these studies are promised for publication as soon as they can be prepared and presented in their proper relation to all of the conditions attending the progress of the work. This survey of the crystalline rocks of the Highlands is done by the United States Geological Survey, according to a plan of co-operation whereby it will study and map, geologically, these formations, and the State will prepare the map of the surface formations and prepare reports on the surface geology.

In the southern part of the State the National and the State Surveys have co-operated in supporting conjointly the work in the Cretaceous and Tertiary formations, and in charge of Prof. William B. Clark, of Johns Hopkins University, Baltimore, Md. The State paid him $300 for expenses in the field, and gave him the assistance of C. W. Coman until the middle of July, when the work was suspended for the season. The results of his investigations, and the

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*The recent establishment of the Algonquin National Park, in Ontario, Canada, by legislative enactment and upon recommendation of a Commission appointed to consider the question, also is instructive. This park, forty miles long and thirty-six miles wide, occupies territory which, in its geologic and topographic features, resembles, closely, our Highlands. It is to be "a public park, forest reservation, fish and game preserve, health resort and pleasure ground for the benefit, advantage and enjoyment of the Province of Ontario."

progress in the preparation of a geological map of the greensand marl belt of the State, are referred to in another part of this report, and also more in detail in the special report on the work made by Prof. Clark.

GEOLOGICAL SURVEY EXHIBIT AT THE WORLD'S COLUMBIAN EXPOSITION.

The preparation necessary for a proper exhibit of the rocks, minerals, ores, building stones, clays, marls and other natural products occurring in the State, at the exposition to be held in Chicago in 1893, was begun in the summer and was carried forward to the end of the field season. In the northern part of the State, Harry Landes, a geological assistant of Dr. J. E. Wolff, of the United States Geological Survey, was at work for three months collecting rock specimens representing the various formations, from the oldest crystalline schists up to the Triassic sandstones and traps. Specimens of building stones from the active quarries, limestones used for lime and cement, shell marls from marl beds, and a few clays, were also collected by him.

The iron ores from the mines then worked, which are to form a principal part of the State exhibit, were collected by Frank L. Nason, geologist on the Survey staff, in the field season of 1890.

Henry S. Gane, assistant to Prof. William B. Clark, and a geological student at the Johns Hopkins University, Baltimore, was employed nearly all of the summer and autumn in collecting fossils from the greensand marl beds and specimens of marls, soils, clays and other natural products of economic importance in the southern part of the State.

Hatfield Smith, general assistant of the Survey, also collected soils from the central and northern counties.

The material brought in this year by these collectors will make a valuable addition, and will fill many gaps in the Survey collections now in the Geological Rooms in the State House. It is proposed to make a selection of the more representative economic specimens and the choice minerals for the State exhibit to be sent to Chicago. It is to have its location in the Mines and Mining Building of the Columbian Exposition. The cost of the field work in collecting has been paid, on presentation of bills, by the New Jersey Commission. The cost of the exhibit is to be borne by this Commission.

OFFICE WORK.

The direction of the various divisions of work carried on by the Geological Survey, and the correspondence in answer to inquiries relative to the State and its geology and resources, and personal attention

to callers seeking information, make up the greater part of the office work, and claim much of the time of the State Geologist. The number of inquiries continues large, and the range is wider than ever before. Whatever can help in the development of the resources of the State is sought for at this office. These inquiries are answered as fully as time allows, that the information thus given may be of service to the people. It is a guiding principle that the Survey owes it to the State to do all that it can to promote its development and prosperity, and therefore careful attention is given to this part of the general work. The many inquiries which call for chemical work suggest the importance of a chemical laboratory, to supplement the office in answering these inquiries, as well as in making some investigations wanted for proper descriptions of materials noticed in the reports.

The distribution of publications is done in part at the office. It embraces (1) that to the public schools of the State, paid for out of the school fund; (2) the distribution of reports to individuals; and (3) the sale of the maps of the atlas of New Jersey. The sale of maps is attended to at New Brunswick, and is in charge of Mr. Upson.

GEOLOGICAL ROOMS.

In accordance with the directions of an act of the Legislature passed in 1890,* the State House authorities have assigned to the Geological Survey a room on the third floor of the old library extension of the State House for the exhibition of its collections of geological specimens, of fossils, ores, minerals, clays, marls, building stones and other natural products occurring in the State, which are illustrative of the geologic structure and occurrence, or are of value in the arts and capable of use in the development of the resources of the State. The Superintendent of the State House has had the cases from the old State museum repaired and placed in the room. They furnish in part the necessary equipment for the exhibition of these collections. Cases along the walls at the ends of the room are needed to complete its furniture and give space enough for the proper showing of what is already in the possession of the Survey, and suited for the illustration of the State's resources. It is proposed to have the relief map of the State placed in the center of the room after its return from the World's Columbian Exposition.

Space will be afforded for the storage of some specimens which are called for occasionally, to illustrate modes of occurrence and variations in character, in personal interviews with parties seeking information on special subjects of inquiry. At present the greater number of such specimens are stored in the basement rooms of the State House, and

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* Laws 1890, chap 222.

are so packed in boxes as not to be readily accessible. The carefully-selected and representative collections placed in cases in this room, when arranged properly and with additional cases, so as to economize fully the space assigned to this use, will make a useful and attractive exhibit of what the State has of geological and mineralogical value and interest.

The maps and reports on hand are stored in the State House basement, except a small part of the stock of maps at Mr. Upson's distributing office in New Brunswick. The surplus stock of maps printed for the exclusive use of the public schools of the State is also stored in the basement, subject to orders occasionally for copies to new schools or others not supplied.

PUBLICATIONS.

The publications of the year have been the annual report and the second volume on the Paleontology of the Raritan Clays and Greensand Marls. The latter consists of a monograph by Prof. R. P. Whitfield, of the American Museum of Natural History, New York, and is from the United States Geological Survey. It is entitled "Gasteropoda and Cephalopoda of the Raritan Clays and Greensand Marls." It was prepared by the United States Geological Survey, and one thousand copies in sheets were furnished to the State upon payment of the cost of paper and printing. This edition has been bound as a State publication, uniform in style with the first volume, which appeared in 1886. A third volume by the same author will complete the report.

The volume on Water-supply and Water-power, and making one of the series of the final report, is not yet ready for publication.

New editions of sheets of the atlas of New Jersey have been printed, to meet the large demand for them.

STAFF OF THE SURVEY.

Prof. Rollin D. Salisbury continues in charge of the survey of the surface formations. Prof. G. E. Culver, Charles E. Peet and H. B. Kummel were salaried assistants in the field. G. N. Knapp and A. B. Whitson were volunteer assistants.

Charles W. Coman, Assistant Geologist, was with Professor Clark from May until in July, when he was transferred to Professor Salisbury's party, in Monmouth county.

Irving S. Upson has continued to have charge of the distribution of publications from New Brunswick. He is also the disbursing officer of the Survey.

Clarkson C. Vermeule, Consulting Engineer and Topographer, has continued his studies and surveys on water-supply and water-power, preparatory to a report on these subjects.

In co-operation with the United States Geological Survey, Prof. William B. Clark, of Johns Hopkins University, Baltimore, was in the field until near the end of July, studying the Cretaceous and Tertiary formations. He was assisted by C. W. Coman and H. S. Gane. In the Highlands, the field work in the study of the crystalline rocks was in progress, under the direction of Dr. J. E. Wolff, of Harvard University and of the United States Survey. He was assisted by Harry Landes.

Alfred A. Cannon has continued as clerical assistant in the distribution of publications, under Mr. Upson, at New Brunswick.

Hatfield Smith is general assistant at Trenton.

UNITED STATES COAST AND GEODETIC SURVEY OF NEW JERSEY, 1892.

BY EDWARD A. BOWSER.

In the month of April an observing tower 48 feet high was built at Taylors, to enable us to see over the tall timber on the lines to Williamstown, Colsons, Lippincott and Pine Hill; and in June a reconnoissance was made for opening vistas through the tree-tops from Taylors to Lippincott and Pine Hill.

On July 13th field work was resumed. Observing signals were erected at Colsons, Lippincott ('92), Pine Hill and Williamstown. The measurement of the horizontal angles at Taylors was begun on July 20th and completed on August 17th.

The old Coast Survey station at Lippincott was made in 1843, and was marked with an underground mark and a surface mark. The surface mark was afterwards removed and lost. At different times, Coast Survey parties searched for this station, but were never able to find it. The Lippincott hill is quite level for more than an acre, and there is not the slightest clew for digging, as the whole hill presents the same smooth and unvaried surface. We therefore erected a signal as near the old station as we could tell, and called it Lippincott ('92) to distinguish it from the old station, which we called Lippincott ('43). The object of observing on Lippincott ('92) was to determine its latitude and longitude, so that, having the latitude and longitude of Lippincott ('43), we could compute the distance and direction from the former to the latter.

After completing the observations on August 17th, the relative positions of Lippincott ('92) and Lippincott ('43) were computed to be as follows:

Distance, Lippincott ('92) to Lippincott ('43)..................... 74.37 feet.
Azimuth " " .... 87° 49′.

We then measured this distance and direction, and dug for the old mark. On August 18th, the underground mark at Lippincott ('43) was found—a frustum of a glazed stoneware cone—about 2 feet below the surface, 75.1 feet from Lippincott ('92), azimuth 87° 6′. The cone was as bright and smooth as if it had been placed there but yesterday.

We then remarked Lippincott ('43). The cone was sunk to the depth of 4.5 feet, and a granite monument was put over it, which is 3.5 feet long, dressed 6 inches square at one end for a length of 6 inches, with the letters U. S. cut in each of the four sides, and a triangle on the top. This monument was set in hydraulic cement to within 6 inches of the top, and a full description, with sketch, was made.

A signal was erected at Lippincott ('43), and the angle Colsons-Lippincott ('43) was measured at Taylors. The theodolite was then moved to Colsons and the angle Lippincott ('43)-Taylors was measured. On September 8th the instruments were moved to New Brunswick.

From September 8th to September 12th a reconnoissance was run on the line Lippincott-Burden, for the purpose of determining the height of scaffold necessary at Lippincott to see Burden. It was found that a scaffold 32 feet high at Lippincott would be sufficient.

In September the latitudes and longitudes of a number of points were computed, including Taylors, Clayton Church spire, Whiglane, Monroe, City Hall tower, Philadelphia, and Lippincott ('92).

The next stations to be occupied are Pine Hill, Lippincott, Burden and Bridgeton, requiring observing towers about 32, 32, 64 and 64 feet high respectively, and probably a long vista will have to be opened through the tree-tops on the line Burden-Bridgeton.

PART I.

SURFACE GEOLOGY.

REPORT OF PROGRESS

BY

ROLLIN D. SALISBURY.

LETTER OF TRANSMITTAL.

Professor J. C. Smock, State Geologist, Trenton, N. J.:

DEAR SIR—During the past summer, work on the Pleistocene (surface) formations was prosecuted as actively and as long as time and means permitted. During the season I spent four months in the field, and had the assistance, for longer or shorter intervals, of Prof. G. E. Culver, and Messrs. C. E. Peet, H. B. Kummel, G. N. Knapp and A. R. Whitson, the last two being volunteer assistants. Mr. C. W. Coman, who assisted Prof. Clark during the early part of the season, subsequently gave much attention to the surface formations of Monmouth county and its surroundings. Some of the surface formations of this region are doubtless Pleistocene, and, therefore, fall within the province assigned me. During the early part of the season, also, by courtesy of the United States Geological Survey, Mr. F. C. Schrader gave some assistance without expense to the State.

The Pleistocene formations of the area covered by sheets 6 and 7 of the topographical map of the State, have been studied with some care. Before the publication of maps embodying the result of work already done, some further study should be given to special points, but the greater part of the field-work for these areas has been done. In addition, some progress has been made in mapping the surface formations in the areas covered by sheets 2, 5, 8 and 9. Some time and attention, too, have been given to various questions of a general nature, the consideration of which was a necessary antecedent to satisfactory work in mapping.

Some of the results which, it is hoped, may be of general interest to the citizens of New Jersey are embodied in the following report, which has been written quite as much for the sake of the citizens of the State who desire to familiarize themselves with geology of the surface formations, as for geologists who may not be familiar

with this particular region. Many of the details now in our possession, concerning the surface formations of the State, are not here presented. Many of these details will be used at a later time, when the surface formations, as a whole, have been studied.

During the prosecution of our work, we have been assisted frequently by the generous hospitality and the kindly aid of many citizens, of whose active and intelligent interest in the work of the survey it has been a pleasure to know.

ROLLIN D. SALISBURY.

December 20th, 1892.

SURFACE GEOLOGY—REPORT OF PROGRESS.

1892.

BY ROLLIN D. SALISBURY.

SECTION I.

INTRODUCTORY—DEFINITIONS.

In the annual report of 1891, a general outline was given of the course of events in New Jersey during the glacial period. It was indicated that during the early part of the period the ice came down from the north, overspreading the northern part of the State and extending southward to a limit which has not yet been determined. It was indicated that, subsequent to this major advance, the ice receded to the northward, freeing the State, and perhaps the United States, from ice. It was also indicated that, during a later time in the course of the ice period, the ice again advanced over a part of the territory which it had earlier invaded, but that it did not reach so far south as during the earlier epoch. It was further indicated that the terminal moraine crossing the State from Perth Amboy to Belvidere was the product of this last great ice invasion, and marks approximately its limit. It is regarded as possible that there may have been other advances and recessions of ice between the first and last glaciations, but evidence that such was the case has not yet been found in New Jersey. It was stated in the report referred to, that the interval between the first and last glaciations in New Jersey was believed to be very long compared with the lapse of time since the last. It was long enough, it is believed, to have allowed the erosion of rain and rivers to have carried away a large part of the drift deposited by the first ice-sheet, and to have allowed that which remained to become deeply oxidized and much disintegrated.

During the past summer the drift deposits of some portions of the State have been examined, both within and without the moraine, with a view to their representation upon maps. The various types of surface formations which have been actually recognized, embrace nearly all of those described in the preceding report as connected with ice formations in general. Some of these types are represented in but few localities. Others are of frequent occurrence and of great extension, and will constitute large areas upon the maps. That there may be no chance of misunderstanding the terms used in the following pages, the leading features of the various classes of drift formed directly or indirectly by glacier ice, are stated in brief terms at the outset. In addition, two or three types of surface material not connected with the ice are mentioned.

1. TILL—GROUND MORAINE—BOWLDER CLAY.

The material carried forward in and beneath the ice and finally deposited from its under surface, constitutes the *ground moraine.* The terms *bowlder clay* and *till* are also applied to the material of the ground moraine. The ground moraine may be composed principally of bowlders or smaller pieces of rock, of sand or of clayey material, or of these various ingredients mixed with each other in any proportion and with any degree of intimacy. Ground moraine is generally compact, doubtless as a result of the compression to which it was subjected beneath the ice-sheet.

More or less material was doubtless carried forward within the ice rather than beneath it. Some of this may have been very near the bottom, and may have been crowded up from beneath. Some of it may have been further above the bottom of the ice, and may have come from the tops of the hills or mountains which projected up into the ice-sheet as it passed over and around them. Material carried forward in the ice is, during its journey, *englacial;* but as the ice melted, the englacial material became, of necessity, either superglacial or subglacial. If it became subglacial, either from the melting of the ice below or because of its descent through the ice, it was deposited from the under surface of the ice, and was therefore subglacial so far as its deposition is concerned. If, on the other hand, the englacial material reached the upper surface of the ice, either as a result of the melting of the ice which overlay it, or for other

reasons, it was deposited from the upper surface of the ice along the line of its terminus, and so was superglacial so far as its deposition was concerned. Such material is often called *superglacial till.* The term "upper till" has also been used in connection with it, but since this term often has another meaning it will not be used in this connection. *Till* and *bowlder clay*, therefore, are terms somewhat more general than ground moraine, since they include also certain superglacial deposits. The term *englacial till* has sometimes been used, but since englacial material must become superglacial or subglacial before its final deposition, the question may be raised whether the term is needed to distinguish any class of glacial deposits. The term is useful to designate the materials which are carried in the ice before their deposition.

Superglacial material is not always sharply marked from subglacial. In general, its bowlders are believed to be more angular, less worn and of more distant origin. It was, doubtless, less compact than subglacial till at the outset, because it had been subject to less pressure. It probably contained less fine material,* since it had been subject to less grinding action; but the exposure of subglacial till to the rains and the droughts, to the heat and the frost, to the plants and the animals for thousands of years, has had the effect of loosening its surface portions to the depth to which these agencies work, so that it may be fairly questioned whether lack of compactness can now be safely relied upon as a criterion for distinguishing the two types of till. In the mapping of the drift formations of New Jersey, no attempt will be made to separate the superglacial till from the subglacial.

2. TERMINAL MORAINES.

The material carried down by the ice to its edge does not differ materially from that which failed to travel so far; but where the edge of the ice stood for a long period of time there would be great accumulations of debris. The material accumulated at and beneath the margin of the ice, while it occupied an approximately constant position, constitutes a *terminal moraine.* So far as it was deposited

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*There is reason to believe that the wind sometimes blew dust upon the ice in large quantities. Locally, the accumulations thus made were so great as to constitute a marked exception to the general absence or paucity of fine material in the superglacial drift.

directly by the ice without the intervention of water, it resembles till in composition and structure. It is, indeed, till. Both superglacial and subglacial material contributed to the formation of the terminal moraine, though the latter more generously. The character of the terminal moraine material, as deposited by the ice, was often much modified by the action of the water which issued from the edge of the melting glacier. Speaking in general terms, the terminal moraine is a rough, irregular, complex ridge of drift, deposited in part directly by the ice, and in part by the waters which were active at its margin during the time of its accumulation. The time of its accumulation was a time during which the edge of the ice remained stationary, or nearly so, for a considerable period of time. The most distinctive single characteristic of the terminal moraine is its undulatory topography, which is often designated a "knob and basin" topography.

3. OVERWASH PLAINS AND VALLEY TRAINS.

Overwash plains.—The material which lies outside the moraine, and which is believed to be of equal age with it, consists mainly of the gravel and sand carried on beyond the ice by the running waters which emanated from it. Where the waters issuing from the edge of the ice found no valley to receive them, they deposited their burden upon the territory just outside of the ice, building up sand and gravel plains. Such plains slope somewhat promptly away from the moraine, and the deposit of sand and gravel grades off to a thin edge at no great distance from the ice. Such a plain is known as an *overwash plain*, or sometimes as a *morainic apron.*

Valley trains.—If the waters issuing from the ice found accessible valleys, the concentration of waters within them caused the currents to be swift, and increased the transporting power of the water quite beyond that of such waters as did not find valleys. Swollen by the floods of the melting ice, the rivers occupying the valleys were able to carry away from the ice great quantities of gravel and sand. This they deposited along the course of the valleys, building up gravel and sand flats, just as rivers are building up flood plains nowadays, except that the process was more rapid and the materials coarser in the ice period than in most existing streams. Such a river flat, constructed of materials emanating from the edge of the

ice, is known as a *valley train.* It is composed of coarser materials near the point where the water left the ice, and of finer and finer materials at greater distances from the same.

Subaqueous overwash plains.—It sometimes happened that marginal lakes existed along the ice front. Where this was the case, the waters issuing from beneath the ice carried their load of debris into water instead of spreading it out upon the land. Under such circumstances, the velocity of water coming from the ice was checked suddenly upon its entrance into the lake. As a result, it was forced to give up its detritus promptly at the point where it reached the lake. Only the very fine material, the finest silt and mud, would be carried out to any considerable distance from the border of the lake. Such material as was carried out a considerable distance from the shore was spread out as a film over the bottom of the lake. The gravel and coarser sand filled up the marginal parts of the lake near the entrance of the glacial drainage. The gravel plain thus constructed would possess a gently-sloping surface, declining from the shore of the lake. The outer margin of the plain would be somewhat lobate, and would possess an abrupt slope, whose maximum angle of descent would be the angle at which loose material, like gravel, would lie beneath the water. Gravel plains developed at the borders of the lakes would gradually advance into them after the fashion of deltas; but, meanwhile, the parts first constructed would be built up above the surface of the water, and come to possess a surface comparable with that which characterizes overwash plains which have no relation to lakes. No specific name is in universal use for such formations. They are overwash plains, formed principally beneath the surface of bordering lakes, and may appropriately be called *subaqueous overwash plains* or *delta plains.*

4. ESKERS—OSARS.

Eskers or osars is the name applied to certain well-defined ridges of more or less completely-stratified drift. Eskers are believed to be always constructional ridges—that is, they are ridges which were built up. They are not ridges which were left by the removal of the materials on either hand. Eskers are extended in a direction which generally makes some considerable angle with the former edge of the ice. They are most commonly more or less parallel with the

direction of the ice movement. Eskers are sometimes nearly straight, but if they have considerable length they are generally winding. Their courses resemble the courses of rivers. They sometimes possess tributaries as do rivers. They are supposed to represent beds of glacial streams in which large quantities of gravel and other drift materials accumulated. The circumstances of accumulation were such that when the ice disappeared, the river whose channel the esker represents, escaped from the course to which the ice had heretofore confined it, and the gravel accumulated in its bed came to stand out as a ridge. It is probable that either superglacial or subglacial streams may thus leave records of themselves. The essential condition for the formation of an esker is the confining of a glacial stream to a definite channel, and a sufficient supply of detritus. Under these circumstances, the beds of streams might be built up to considerable height by the accumulation of materials within them. Had a stream been able to leave its bed as it was being built up, ridges, or channel accumulations which might become ridges when the ice melted, would not have been formed. Eskers formed in valleys beneath the ice would not suffer disturbance by the melting of ice beneath them, since there was no ice there to be melted. Eskers formed in superglacial channels would have been let down irregularly if there were inequalities in the rate of melting of the underlying ice, and would be less likely to remain as sharp ridges. Superglacial eskers, too, would be likely to lose much of their definition as the ice beneath them melted. The gravel would protect the subjacent ice from the sun's rays, and would presently come to rest on a ridge of ice from which it would slide off on either side, thus broadening, if not destroying, the ridge. How often this happened we have no means of knowing. But where this happened we have no esker. By whatever method they came into existence, eskers would be subject to disturbance and destruction by any movement of the ice which affected the regions where they had been deposited, after the period of their formation.

5. KAMES.

Certain hills or short ridges of stratified sand and gravel are called *kames*. They owe their form mainly to deposition, and not to any isolating process subsequent to their deposition. They occur singly, in groups, or in belts. They are pre-eminently phenomena of

the margin of the ice, but since the ice margin was, at some time, at all points covered by the ice, kames are not confined to the limit of ice advance. They are frequently associated with terminal moraines, and are often constituent parts of the belts designated terminal moraines. The stratification of kames is often very irregular and frequently distorted, as if they had been subjected to the action of some disturbing agency after they were formed. Their stratification is often such as to show that the water concerned in their formation had great velocity.

6. LACUSTRINE FORMATIONS.

The ice-sheet was frequently so situated with reference to valleys as to interfere with drainage by damming the streams. Under these circumstances, lakes or ponds were likely to be formed. When the ice, in its forward movement, reached a land surface which was inclined toward it, there would be a trough-like depression between the ice on the one hand and the land on the other. In such situations, ice-water might accumulate, forming a lake. Whenever, from any cause, surface-waters found no outlet, bodies of standing water were formed. If strong gravel or sand-bearing streams did not enter such lakes or ponds, there would still be some drainage into them, both from the melting ice and from the adjoining land. The inflowing drainage would bring more or less sediment. In the absence of streams, it would be of a fine mud-like character; in the quiet water of the lakes and ponds this sediment would settle down over the bottom, mantling its elevations and depressions with something of regularity. Clayey sediment thus deposited would possess certain characteristics which do not belong to clays or clayey deposits made by the ice directly. Since only the very fine materials could be carried out into the lake, the deposit thus made would be wanting in the coarser materials which characterize the glacial drift. Lacustrine clays, as distinguished from glacier clays, would thus possess greater uniformity of texture. They would also be much more waxy (fatter) than those of coarser or more heterogeneous constitution. They contract and crack upon drying much more readily than do other classes of drift deposits. They possess certain other distinctive characteristics less susceptible of clear definition and brief statement. These lacustrine clays occasionally contain bowlders, as

well as stones of smaller dimensions. These were probably floated out by icebergs and dropped into the mud accumulating at the bottom of the lake during the accumulation of the clays. About the borders of lakes coarser materials, such as sand and gravel, might accumulate to great depths if inflowing streams or the waves of the lake supplied the necessary material. Subaqueous overwash plains and wave-built terraces, as well as other shore features, might thus arise. The coarser material of the shores would grade into the finer material of the deeper water.

7. BERG TILL.

When icebergs bearing till or bowlders floated out into lakes which bordered the ice-sheet, deposits were made in the water which bear resemblances both to till and to lacustrine clays. If the icebergs bore till, this might be deposited intact if the icebergs grounded. If the bergs bore only bowlders and stones, these were dropped into the lacustrine clay. The stones and the clay or mud might be in the relative proportions appropriate to till. Such deposits would be, in some respects, unlike ground moraine, both in physical constitution and in topography; but the two classes of deposits may so closely resemble each other that their local differentiation is no simple matter. Deposits of *berg till* are quite certainly existent in New Jersey.

8. ALLUVIAL PLAINS.

Rivers are commonly looked upon as destructive agents. They are primarily valley-makers, but under certain circumstances a river becomes a constructive agent. If a stream be swift in one part of its course and slow in another, the swifter part may get a load which the slower cannot carry. Deposits will then be made in the valley where the current is sluggish. In this way flood plains are constructed. Flood plains produced by the filling of a valley bottom are alluvial plains. We commonly think of alluvial plains as made of fine mud, but alluvial plains may be made of sand or gravel, under the proper circumstances. The nature of the material will depend upon the absolute and relative velocities of the stream in different parts of its course, and upon the nature and amount of the material

which it is eroding and carrying. Alluvial plains once constructed may be partially removed by a river in a later stage of its history. If a river sink a new channel so deeply below the surface of its old flood plain that this plain ceases to be flooded, the remnants of the old flood plain become terraces. Many river terraces are, in reality, no more than alluvial plains which the river no longer floods.

9. WIND-DRIFT—DUNES.

Wherever sand is exposed in such situations that it becomes dry frequently, and where the wind has access to it, it is likely to be shifted in position. If it is heaped up in hillocks or ridges they are called *dunes*. If the sand is drifted by the wind without being accumulated in hillocks or ridges, it is sometimes called *wind-drift* or *dune sand*, as distinct from dunes. These terms are applied to material drifted by the wind only where it is accumulated in considerable quantity. In all dry regions the wind is constantly shifting the fine material of the surface. Even in regions which are always moist, dust blown from other regions is continually settling from the atmosphere, however slowly. Material drifted by the wind is, therefore, well-nigh universal. But so long as it remains a minor constituent of the surface earths, the earths of which it is the minor constituent are not known as wind-drift.

10. RESIDUARY EARTHS.

Residuary earths are not drift in any proper sense of the term. They are the residue of rock decomposition, which has escaped removal from the site of its origin. The residuary earths are mainly the insoluble, or less readily soluble parts of the rock which gave origin to them. It rarely happens that residuary earths now lie exactly where they originated. Where they originated on hill crests or hill slopes, they have gradually descended, accumulating at lower levels. This transference downward is effected in various ways. When saturated with moisture, surface earths become more or less plastic, and have a bodily downward motion of exceeding slowness, under the influence of gravity. The residuary materials from above tend thus to accumulate at the bases of the slopes on which they originated. Again, every shower which causes water to pass down-

ward over the surface of a slope, effects the transference of surface particles of earth from higher to lower levels. This transference differs from that last mentioned only in this, that in this case gravity effects the movement of the water which becomes the vehicle of transport of the earthy particles, while in the other, gravity effected the transfer of the earthy materials directly, the moisture inducing a sort of plasticity. The wind likewise assists in shifting fine material from its place of genesis. Burrowing animals move surface materials by direct means, and, by keeping the soil loose, indirectly facilitate transference by other means.

Plants do a similar work in keeping the surface soils loose. On the other hand, they retard the movement of surface materials by means of their roots, which tend to hold the materials together, and to prevent their movement. Their retarding influence is doubtless much greater than the opposite. But locally, as where trees are uprooted, the loosened earth is brought into a position favorable for shifting down slopes. After the scars made by the uprooting of trees are healed, the vertical as well as the horizontal relationship of surface material will have been altered, for a part of that which was before at the surface may now be buried. So, also, when the roots of plants decay, the spaces vacated may be in part filled with material which has descended from the top, so that what was once surface material may come to be deeply buried. Residuary earths in any given locality may therefore be made up of materials of different sorts, brought together, though not usually from great distances, by various means.

A diversity of material is sometimes brought about by contributions from various layers of rock in vertical succession. A stratum of rock which has entirely disappeared as a solid layer, may have left a residuum which may be mingled with she residuum from a lower layer now being disintegrated. By vertical descent, as well as by lateral shifting, therefore, residuary material may come to be somewhat heterogeneous in character.

11. MISCELLANEOUS TYPES OF DRIFT.

Gravel, sand or other sorts of loose material, with the origin of which neither ice nor wind had anything to do, may be found upon the surface. Rivers bring down from their upper courses such

materials as there exist, and spread them along their valley bottoms further down stream (alluvial plains). Rivers sometimes shift their courses. The origin of materials scattered over the surface along the abandoned course of a stream or along the former course of an extinct stream might not now be evident. Such materials would not be classed as alluvial. To such materials the term *drift* is not inapplicable. So too, the temporary submergence of a given area might be the occasion of deposition of gravel, sand or other material upon it. If subsequently this origin were made obscure, as might be, the material might be called drift, since it appears to have been drifted in from some other source, to its present position. While, therefore, the term drift in the northern United States is commonly understood to mean glacial drift, the same term is sometimes used to denote other formations as well. In this event some qualifying term is usually prefixed.

Criteria of Discrimination.

Where ideally developed, there is little difficulty in discriminating between ground moraine, terminal moraine, kame, esker, sand plain, &c. But when it is remembered that each type of drift may pass over into each other type by all degrees of gradation, either laterally or vertically or both, it will be seen that there are great difficulties in the way of sharp and accurate definition. A map must be definite. The drift formations are not always so. The areas of gradation and mixture of types are so many and so ill-defined that the types cannot always be sharply differentiated. In their delineation upon maps, absolute accuracy as to details would be impossible on a map on any scale which it would be practicable to use—probably on any scale whatsoever.

Were there everywhere sufficient exposures of the drift, or were there at sufficiently frequent intervals sufficient exposures of the drift, its real nature might be everywhere accurately determined, even if it were not possible to represent all the details on a map. But it frequently happens that over wide areas there are no exposures, or only very meager ones, and that their testimony is contradictory or equivocal. In such cases we are compelled to decide between the several types of drift by other means. The expedients resorted to, and the means made use of, are various.

Topography is a good index of the nature of the drift. Till often

has a topography more or less distinctive. On the basis of topography, till may generally be separated from kames, eskers and terminal moraines, and even from overwash plains; but it would often be very difficult to differentiate till from certain unclassified sand and gravel areas, on the basis of its topography. Topography alone is often an unsatisfactory criterion, and it generally happens that the criterion fails in just the areas where it is most needed. That this should be so is probably the result of the fact that the areas where other criteria fail, are areas where no type of drift exists in its simplicity. They are probably the areas where the different phases of drift are much commingled.

Where there are no exposures, and where the topography is indecisive, vegetation sometimes serves as an index, though never a satisfactory one, of the nature of the subsoil.

The various phases of drift sustain certain more or less well-defined relations to each other. Where neither exposures, nor topography, nor vegetation, nor all combined seem conclusive, the associations of the uncertain areas may afford some clue as to their probable nature.

In addition to these criteria, the testimony of those who have made excavations in the drift is often sought. Such testimony sometimes affords satisfactory evidence, but it is often far from satisfactory. It might seem at first thought an easy matter to distinguish between gravel and sand on the one hand, and till, which is usually clayey and tough, on the other. And so it would be if each type always preserved its ideal character; but since it does not, and since there are all possible gradations between them, it is often difficult to tell from small excavations, such as borings, whether the material belongs to the one category or to the other. Especially is this the case where the excavations were made years since, as most of them were, by men who paid little attention to these questions, and who have forgotten much of the little they did observe. It will be seen that reliable data are hardly to be obtained by this means. Then, too, what one man calls gravel, another calls hard-pan, and *vice versa*. In many regions the whole bed of drift is called gravel. The till of many regions is gravelly; so much so that its real origin would be manifest only to him who examined it with this especial purpose in view.

Even when all these means are made use of, the results are often

not decisive. The different lines of evidence are so obscure, or, for one reason or another, so unsatisfactory and inconclusive, as to afford no more than an insecure basis for conclusions, and it not infrequently happens that the different lines of evidence seem to point to different conclusions. With all available means of discrimination, there still remain considerable areas whose real nature is in doubt. It would be better to map such areas as unclassified drift, and in the future this will be done. The need for recognizing such a class of drift was not appreciated at the outset, and the attempt was made to put everything into one class or another. This was done on slender evidence, when only slender evidence was at hand.

4

SECTION II.

TILL.

Probably no other phase of the drift is capable of assuming more diverse phases than the till. One source of diversity is variation in the character of the underlying rock; a second is the ever-varying topography of the country affected by the drift; a third is the diverse origin of the till, as subglacial or superglacial; and a fourth is the extent to which its nature was altered by the action of water at the time of its deposition.

Superglacial till.—In the Highland region of New Jersey, where the underlying rocks are crystalline schists and gneisses, and where the preglacial topography was rough, in many places even mountainous, the till is sometimes thin and locally largely composed of bowlders. Several causes conspire to produce this result. The character and condition of the rock was such as to give rise to abundant bowlders. The topography was such that the finer products of rock disintegration were largely removed by subaërial erosion before the invasion of the ice, so that the latter worked upon a rough surface generously strewn with loose blocks of rock, and capable of yielding many more under the rough mechanical action of the ice. The steep gradients made the action of the glacial waters vigorous, one result of which was the removal of much of the finer material which the ice itself might have produced, thus increasing the proportion of coarse material in the deposits actually left upon the surface by the ice.

In such regions there are frequent exposures of rock. Where the till is present but thin, and composed mainly of angular bowlders, it is not impossibly mainly of superglacial origin. Especially may this be true upon the steeper slopes of mountainous regions, where subglacial waters were probably most effective in removing such fine materials as might otherwise have accumulated beneath the ice. That the material in some such situations is in part superglacial seems to be indicated by its lack of compactness, and by the angular and unworn character of its bowlders, even where it rests on rock which is scored and polished in true glacial style. Till of this loose, bowldery type, often indeed composed of little but unworn bowlders,

is not common in New Jersey outside the areas of crystalline rocks and rough topography. Within these areas it is much less prevalent, even at the surface, than subglacial till. Nowhere has it been observed to attain any considerable depth.

It is frequently true that a thin layer of till, neither demonstrably subglacial nor superglacial, overlies a greater depth of drift which is clearly subglacial. Where the thickness of this surface layer is so slight that it does not exceed the depth to which weathering may have loosened the surface of the subglacial till, and this is generally the fact, it has generally been regarded as probably of subglacial origin, unless something in its constitution or relationship makes another interpretation more rational. But in any case, the amount of superglacial till does not seem to have been great, even in the regions of great relief, where its amount might be expected to be greatest.

Subglacial till.—In contrast with this loose type of drift is the demonstrably subglacial till which covers most of the area where the drift overlying the crystalline rocks is till. In some localities within this area the till has been so thoroughly compacted as to give it almost the appearance of indurated rock. Locally, it has the aspect of a half-formed conglomerate. It is probably the angular and irregular form of the coarser particles imbedded in the clayey matrix, rather than incipient cementation, which helps to bind the whole so firmly together. In some such instances the till is much less completely indurated that it appears. While a section of it may stand with nearly vertical face, and while that face may be so hard that trowel or spade makes little impression upon it, a block of the material, if by any means detached from the section, breaks or crumbles easily. Nowhere is this brittle, semi-indurated type of till better exhibited than in the railway cuts just south of Allendale, in Bergen county; but the type of till here represented is of common occurrence throughout the crystalline schist area.

In addition to its compactness, the till here exhibits, to a marked degree, the peculiar foliation so characteristic of much subglacial and firmly-compacted till. This foliation, which is never developed in superglacial till, is doubtless the result of the pressure to which the ice subjected the material beneath it, and is roughly comparable with the structure which affects crystalline schists. This correspondence concerns both the development of the schistosity or foli-

ation, and the results of this development. Under the great pressure of the ice, the individual particles of the drift tended to so arrange themselves that their longest diameters were at right angles to the direction of pressure—that is, in a horizontal plane. The result is an imperfect, somewhat irregular but more or less horizontal cleavage, similar in kind, and sometimes in degree, to the cleavage of crystalline schists.

Vertical pressure tended to compress the yielding parts of the drift (the clayey portions) and to render them more compact. Wherever pebbles or larger pieces of hard rock occurred in the clay they more successfully resisted the pressure of the ice. Thanks to their unyielding nature, the clay immediately surrounding them was subject to less pressure than that at greater distances, so that foliation or cleavage planes failed of distinct development immediately about resistant stones and bowlders. The cleavage planes developed at a little distance beyond the range of the protecting influence of a given bowlder, may frequently be observed to bend up over it on the upper side and down beneath it on the lower, while laterally on all sides of the bowlder the cleavage structure fails of development for a short distance. Large and small stones produce effects similar in kind but different in degree. Corresponding appearances are often observable in those gneisses and crystalline schists in which resistant pebbles or crystals existed at the time of the development of the schistosity.

There is no surer mark of subglacial till than this foliated structure. Any till in which it is developed is unquestionably referred to a subglacial origin. As a positive criterion, we believe it well-nigh infallible. As a negative criterion, it is worthless, since much subglacial till does not possess it. It would not be developed, for example, in till of which sand or gravel or stony material was the principal constituent.

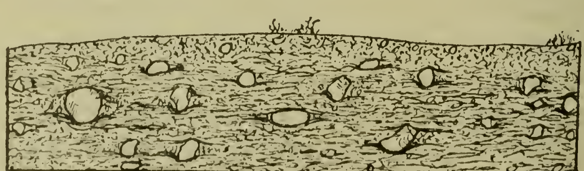

Fig. 1.

Diagram representing horizontal foliation in subglacial till. The lines of foliation are somewhat irregular and discontinuous, and are often bent at the upper and lower surface of the bowlders. All trace of foliation has disappeared from the surface to the depth to which weathering is effective.

Dependence of till on underlying rock.—Till is generally dependent to a large degree on the nature of the underlying rock. Within the area of crystalline schists, the till is composed almost wholly of this rock. The proportion of foreign material is, in most places, surprisingly small. Many a drift cut does not show above five per cent of material which might not have been derived from the immediately subjacent rock terrane, and sometimes the proportion runs down to one per cent or even less. Where the subjacent terrane is of great extent, the material of the drift may be less strictly local than it seems. But the fact still remains that the great bulk of the glacial drift has not been transported any considerable distance, a fact which in itself argues strongly against the superglacial origin of any considerable proportion of it.

Till composed mainly of gneissic material.—Much of the drift within the crystalline schist area has not yet been studied in detail, but most of the area between the Saddle and Ramapo rivers is covered with till of gneissic origin, as also the area between the Saddle and the Wanaque. Aside from the railway cuts south of Allendale, already quoted, this type of till is well exposed west of Mahwah, and at various road cuts in the area between the New York, Lake Erie and Western railway and the Saddle river, north of Allendale. Better than any other type of till, it shows both the foliation and the exceptional compactness already referred to.

Drift composed mainly of Triassic shales and sandstones.—So soon as the crystalline schist area is passed in coming southward, the character of the till changes promptly. Instead of drift composed of crystalline schist materials, more or less comminuted, the till at once becomes more clayey, the matrix being no longer derived mainly from the rocks of the crystalline schist series, but from the rocks which lie beyond, generally the Triassic shales and sandstones. The promptness and extent of this change, sometimes affecting the drift to its very surface, seems to constitute good additional evidence, closely related to but not identical with that just mentioned, against the universal, or anything like universal, presence of a large amount of superglacial drift. Bowlders of the crystalline rocks are by no means wanting south of the crystalline schist area, and may even be the predominant bowlders for miles south of its border. But they no longer constitute the principal element of the drift, and are usually imbedded in a matrix which has a more local origin.

That the Triassic shales and sandstones gave origin to fewer bowlders and yielded more earthy material, is because they are more easily crushed and reduced to a fine state of division. That this is the true meaning of the variation in the character of the till is further shown by the fact that it is more clayey where the underlying rock is shale, and more sandy where it is sandstone.

In the early history of glacial geology in northeastern New Jersey, it was customary to speak of "red-shale drift" in distinction from the "yellow-gravel drift." This early nomenclature expresses a fact which is obtrusive enough in the southeastern part of the region covered by the drift of the moraine period. But the designation "red-shale drift," which was applied only locally, would not be applicable to any area north of the red-shale country. The name is most appropriate when applied to the glacial drift of the Triassic area, as indicating the extent to which the red shale contributes to the drift where it is the subjacent rock. In the way in which the term was originally used it is significant, since the outermost border of the last glacial drift in the eastern part of the State is uniformly red, while much of the gravel beyond, which was designated "yellow-gravel drift," has, as the name implies, almost no material derived from the red-shale formation.

In many places within the Triassic shale area, usually somewhat remote from the crystalline schists, the till is often nearly free from bowlders and all forms of stony material. The distant formations did not furnish the coarse material, and the formations close at hand are so soft that detached masses failed to withstand the crushing and grinding action to which they were subjected. No better example of this clayey, nearly stoneless till is known than that which was exposed by an excavation in Chatham during the summer of 1892. The till here is little more than pulverized red shale, so finely comminuted as to be of a clay-like consistency, with rarely a local or foreign bit of rock of more resistant nature. In such cases it is not rarely true that the bottom of the till is very stony, the stony material being no more than blocks of subjacent rock, merely loosened and slightly shifted from their original position. The blocks least moved are large and hardly worn or broken. Those whose shifting has been a few feet more, show more wear and disruption, and at no great distance they lose their integrity altogether. Sections of till of this character, unmixed with large amounts of foreign material,

seem to give a rough measure of the amount of transportation the loose blocks of non-resistant shale or sandstone are capable of enduring, under the conditions of ice action, without reduction to sand or clay.

Till composed mainly of red shale or sandstone is exposed at various points in the ridge running east of north from Rutherford through Corona to Hackensack (Culver). It is also well shown at various points east and southeast of Paterson, in East Paterson along the north edge of the park, and along the west face of Palisade ridge, especially in the area south of New Durham. Again, in the vicinity of Montclair (Peet), there are numerous roadway and railway cuts showing red-shale till. In Newark, especially in the western part of the city, there are good exposures of red-sandstone till. Till, likewise composed mainly of Triassic material, is exposed between Newark and Irvington (Peet). It is well shown in the deep railway cut near Fanwood, northeast of Plainfield, though this is within the terminal moraine belt. It overlies much of the clay district about Woodbridge, and is exposed in many places where pits have been opened. Most of the exposures above noted are so situated as to be more or less permanent. There are many minor exposures in numerous localities. Many temporary exposures not here mentioned may be seen at any time. The localities mentioned are noted only for the purpose of giving localities when the types may be seen.

Trap till.—Where the change in the subjacent terrane is from crystalline schist to trap instead of shale, the till is likewise abruptly changed, but with a very different result. The trap till is as distinctive as the red-shale till. Crossing and recrossing the line marking the junction of different rock formations, one cannot fail to be impressed with the idea that subglacial till is, on the whole, very sensitive to subjacent variations in the rock, and that the variation in the subglacial till is little obscured by any superglacial covering.

Within the areas of trap rock there are many sections of till which show that the principal ingredients of the same are strictly local. The till here is often little more than a mingling of (1) the trap residuary earth already in existence when the ice invaded the region; (2) the earthy products arising from the comminution of trap rock, some of which was already partially disintegrated when the till was made, and (3) the hard bowlders and blocks of trap. The solid bowlders are doubtless in some cases the firm cores of larger trap

masses whose exteriors were disintegrated before the ice invasion, and in others the remnants of blocks quarried out of the trap by the ice itself. This quarrying action of the ice was probably confined, for the most part, to bosses, ledges, and abrupt faces of trap which preglacial erosion had developed, and against which the ice worked.

Till derived mainly from trap is well exposed at Caldwell, along the road leading northeast from the depot (Peet). At most points where drift is exposed on the Palisade ridge, also, the trap type of till may be seen.

AREAS WHERE TILL IS MIXED WITH OTHER TYPES OF DRIFT.

There are many tracts of considerable extent in northeastern New Jersey where the real nature of the drift is exceedingly complex, and where the glacial history must have been correspondingly complicated, though its various stages and factors have not been distinctly separated. Over a somewhat extensive area, lying north and east of Madison and Morristown, a thin but variable layer of till covers a great depth of gravel and sand. There are considerable tracts where nearly every excavation reaching a depth of several feet reveals gravel and sand so disposed as to show that water was the agent of its deposition. In some cases the topography of the drift seems to be controlled mainly by the topography of the gravel and sand beneath the coating of till. An instance in point is the rather level-topped ridge, about a mile in length, running south from a point a half mile west of Parsippany. Seen from the west, this ridge has the appearance of a spit. So clear does this interpretation seem when the ridge is seen from a distance that one is surprised, on reaching it, to find it strewn with bowlders, and the gravel and sand buried, and often deeply buried, beneath till. There can be little doubt that the ridge itself owes its form to water deposition, and that the till coating is superficial only and of subsequent origin, and that it was spread upon the ridge without greatly modifying its topography. A similar relationship of stratified and unstratified drift affects a somewhat extensive area in this vicinity. Though not existing everywhere, it is characteristic of the region extending from Parsippany on the north, through Malapardis and Whippany to near Madison on the south, and to the Passaic river on the east.

Within this area the sand and gravel frequently come to the surface without a covering of till. Frequently, too, the till has so considerable a depth as to completely conceal the sand and gravel.

Taking into account the total thickness of the drift, there is much more stratified than unstratified material throughout this area. While the latter is very often the surface member of the drift complex, it not infrequently re-appears at lower levels, if information concerning deep borings may be relied upon. Such data, however, are liable to misinterpretation. For the most part, information now obtainable from wells and borings tells only whether the beds are composed principally of sand, gravel or clay, and beds composed mainly of any one of these ingredients may be stratified or unstratified. Where sand and gravel predominate it is natural to infer that the material is probably stratified, and where the material is predominantly clayey, that it is till. But these inferences are not necessarily correct. For example, two miles southeast of Whippany, east of the Whippany river, in a cut in the road which crosses the Hanover triangulation hill, there is revealed a stratified clay which is manifestly not till, and of whose deposition glacier ice was not the agent.

It is not impossible that in other situations the "stony clay," said to occur at varying depths from the surface, and which in the absence of other evidence has been interpreted as probably till, really belongs to some other class of drift. Even the presence or absence of stones in buried clayey drift cannot be relied upon as a criterion for the identification of till, since the clay above referred to is charged with concretions of lime carbonate, which are neither infrequently nor improperly called stones, so that "a clay full of stones," even though demonstrably a part of the drift, is not necessarily till.

It will be noted that these phenomena occur in the region in which the supposed Lake Passaic existed. If this lake had a real existence, the phenomena here noted are probably in some way connected with it. To this point reference will be made later.

In many other regions till and stratified drift alternate with each other in thinner or thicker beds, in such wise as to make the reference of the drift to any single type arbitrary. While it can be confidently asserted in many cases that this or that layer of the drift is the product of ice or of water, the surface layer may be quite dif-

ferent in origin from the main body of the drift, and it is the surface layer only (say two or three feet) which can be taken into account in mapping. In many parts of the State, even where the surface layer of the drift is till, the main body of it is stratified. In the north-eastern part of the State, outside the Highlands, it is safe to say that the stratified drift greatly exceeds in mass, if not in area, that which is not stratified.

One region where the till and the stratified drift are much mingled with each other, and in complex relationships, is found near the coast from Newark southward to and beyond the Rahway river. The great quantities of stratified drift at the lower levels in this region,.give point to the inquiry concerning the level of the sea at the time of the last drift deposition. As an offset to the suggestion of lower land or higher sea afforded by the abundance of stratified drift at low levels near the coast, we find in other regions, as at Sewaren and vicinity, typical, firm till, bearing no marks of wave-work or other indications that it was ever covered by the sea-water, running down to the sea-level itself. The phenomena of the coast make it clear that the question of the attitude of the land relative to the sea during the last glacial epoch is not to be determined merely by the presence or absence of sand or till along the coast at or above sea-level.

Till at sea-level no disproof of submergence.—Some data drawn from various sources are at hand touching the general question here alluded to, but they are not of a perfectly decisive character. So far as yet ascertained, the indications that the coast of the State was lower than now during the last glacial epoch, and consequently that the sea was higher with reference to it, are much less decisive and widespread than would have been anticipated had this been the fact. Yet there are some things which are not readily accounted for on any other hypothesis. To them reference will be made later. But it may here be stated that we are not in a position to affirm unqualifiedly that the sea was, or was not, higher or lower than now, relative to the land, along the east coast of New Jersey, during the last glacial epoch, or that any change in their relations has taken place since that event. The solution of this question, until more decisive data than have yet been found reveal themselves, will be difficult.

There is a considerable tract in the vicinity of Rahway, especially

to the northeast, east and southeast, which lies at a level of less than forty feet above tide. It is, for the most part, not covered with stratified drift. Its surface materials simulate till. Yet it is not normal till. It possesses certain characteristics which seem to suggest either that it was formed beneath water or that it has been beneath water since its formation, but without suffering extensive erosion, and without retaining any unequivocal evidence of its submergence. The drift here is, on the whole, more clayey and less stony than most till. It was formerly extensively used for the manufacture of brick, but the old pits, no longer worked, afford no exposures, and excavations of any sort are now few. Wherever they occur the material exposed is of such a character as to seem to ally it with till rather than with any other recognized type of drift. Since the region is very low and flat, and in places ill-drained, it is possible that the features of the drift which have suggested a subaqueous origin, or a subsequent subaqueous modification, may be due to ill-drainage instead. So far as I have been able to learn, no shells or other fossil testimony of the presence of the sea have been found. The material of the drift is of such a nature that shells, once imbedded, would be likely to endure. Concerning the till-like drift of this region, we are not ready to state a final conclusion.

SECTION III.

EXTRA-MORAINIC TILL AND ASSOCIATED DRIFT WHICH IS NOT TILL.

At various points there are considerable areas of till and of material which appears to be till, altogether outside the terminal moraine. This extra-morainic till and till-like material has very various characters, and may not all have had the same history or be explicable in the same way. With it is associated more or less drift material which is not till. From the theoretic standpoint, it is altogether possible that the ice of the last glacial epoch locally, or even generally, advanced beyond the position of the recognized terminal moraine before the latter was made, or that such advance took place now and then during the time of the development of the moraine. In either event the extra-morainic drift would be an appendage of the moraine, and referable to the same ice epoch. Likewise from the theoretic standpoint, there is the possibility that the extra-morainic drift represents a remnant of a glacial deposit of an ice epoch antedating that during which the terminal moraine was made. In this event, it is in no way directly associated with the moraine in point of genesis. There is the further theoretic possibility that the till-like extra-morainic drift may not be strictly glacial, but that it represents the work of water, or of water and icebergs, emanating from the ice of any glacial epoch, and transporting glacial debris beyond the limit of the glacier ice itself. There is the still further theoretic possibility that extra-morainic surface materials may not be in reality drift, but only drift-like, and that they are of local origin, resulting from the decomposition of local rock under such conditions as to leave a product so closely simulating drift as to be mistaken for it. And lastly it is conceivable that this extra-morainic drift may be the work of water in no way connected with the ice of any glacial epoch. In this case it may properly be called drift, but not glacial drift.

To which of these possible origins the extra-morainic drift is to be assigned can only be determined by a discriminating study of its structure, its chemical, physical and lithological constitution, and of

its geographic, geologic, and topographic distribution and relations. When the whole area outside the moraine has been studied in detail, it is not impossible that there will have been found drift, or surface material resembling drift, referable to all the genetic classes here enumerated. At least until the whole area concerned has been critically studied, we have no warrant for referring the whole of the extra-morainic drift to any one, or to any limited number of the above categories. Certain of these extra-morainic deposits may, and we believe do, possess inherent characteristics demonstrative of their origin. But this is not true of all of them.

Criteria for Differentiation.

If the extra-morainic drift be glacial and the product of the last ice-sheet, it should stand in definite geographic relationship to the moraine. It should border its exterior for a limited distance, though not necessarily everywhere. Its border should be fairly well defined, since subsequent erosion has been too slight to effect great changes. It should be extended further from the moraine in valleys and on lowlands, and to lesser distances on ridges and uplands. It should contain inherent evidence of its glacier origin, in the presence of striated or glacially-shaped bowlders and rock fragments, in its compactness, and in the unstratified structure of at least some part of it. It need not be altogether unstratified, since here, as elsewhere, the water accompanying the ice might have been active. Its composition, both physical and chemical, should be similar to that of the moraine close at hand, although not necessarily altogether identical with it.

If the extra-morainic drift be the product of waters emanating from the ice of the last epoch, this genesis should be evident from its distribution, structure and composition. It should find its chiefest development along the lines of glacial drainage, and not on the hills and ridges along the ice border. Its maximum height at the border of the ice-sheet should never be greater than that of the moraine itself, and it should decline rapidly beyond (outside) the same. It should not be found covering hills and ridges separated from the moraine by depressions, even though these hills and ridges be lower than the moraine itself, for waters flowing from glaciers cannot well carry gravel to the tops of even low isolated hills and ridges. In evaluat-

ing the testimony of vertical distribution, due allowance should be made for possible postglacial changes of level. If the extra-morainic drift be the product of glacial waters, it should be stratified, and stratified after the fashion of deposits known to be made in this way. It should be composed of materials which might be derived from the adjacent moraine, and the drift associated with it.

If the extra-morainic drift be the product of an ice-sheet antedating that which made the moraine, it should possess, in its physical constitution, evidence of its glacial origin. If it antedated the later drift by a long interval, its chemical constitution should have been changed in such wise as the processes of weathering determine. Its original constitution need not have been identical with that of the newer drift, since the movement which produced it may have been from a different direction, or if from the same direction the ice may have worked upon formations which have since disappeared. If the extra-morainic drift be referable to the ice of an earlier epoch, its distribution need not be subject to the same limitations as if it be connected with the terminal moraine in time of origin. It need not be best developed near the moraine. It may cover hills and uplands, as well as valleys, outside the moraine. If erosion has been great since the deposition, it may be more prevalent on uplands than in valleys, for from valleys erosion would be most likely to have removed it. Likewise, its border might be difficult of definition by reason of the extensive erosion which may have taken place since its deposition. Its occurrence in patches, isolated by erosion since its deposition, would be expected, if it be of great antiquity.

If the extra-morainic drift be the product of water connected with an earlier ice-sheet, its distribution must have been determined by the general principles of glacial drainage, applied to the topography existing at the time of its origin, and this may have been very different from the topography which obtained during the last glacial epoch. Its present distribution should differ from its original distribution in such ways as subsequent removal and re-distribution might determine. It should stand in definite geographic and topographic relation to the old glacial drift with which it was associated in origin, if the latter were accessible and determinable. In its constitution it should stand in some definite relation to the earlier ice drift, a relation which could be determined if the corresponding glacier drift were recognized.

If the extra-morainic drift be the product of waters not in any way connected with the glacial epoch, its original distribution would have had some definite relation to topography, and its present distribution would be the result of subsequent removal and re-distribution. The material should bear in its structure the marks of its aqueous, *versus* glacial, origin. It should be free from glaciated stones, and those other distinctive features which are the marks of glacier work. It need not stand in any definite relation, areally or topographically, to any body of glacial drift. If its antiquity be great, its distribution might be measurably independent of present topography.

If the extra-morainic drift be residual, and, therefore, not drift at all in the usual sense of the term, it should be made up of local materials only—that is, of such materials as the underlying rock could furnish, together with such materials as could be furnished by strata which once covered the region, but which have now disappeared, and of such further materials as might be brought together by all the various movements of surface materials which are incident to differential degradation. It should not be stratified; it should not possess glacially-shaped or glacially-striated bowlders or rock-bits, though the softer fragments might be covered with such irregular markings as might result from creep and other movements of surface materials down slopes. It should not contain an abundance of well water-worn stone, unless, indeed, one of the contributing formations be conglomerate, which might furnish water-worn pebbles as a residual element. Its distribution should be such as might be accounted for by this method of origin. It should not cover hill-tops or the crests of ridges to any great depth, and should be less abundant on level-topped plateaus than on areas where surface movement would favor its accumulation. It should be found especially on the lower slopes and at the bases of elevations, existent or extinct, which could have supplied the materials of which it is composed.

Areal distribution of extra-morainic drift.—Considerable bodies of extra-morainic drift, possessing the inherent characteristics of drift of glacier origin, are known to occur at various points in New Jersey. They probably occur at some points not yet known. From a point a little north of Morris Plains, nortwestward to Dover and beyond, extra-morainic drift has a considerable development. In a general way, its development is better near the moraine and more

meager at points more distant from it. Taken by itself, this feature of its distribution would seem to be consistent with the hypothesis that it is the deposit of the moraine-producing ice-sheet, at some time when it made a temporary advance beyond the position which it occupied while the moraine was making. So far as its geographical distribution is concerned, this part of the extra-morainic drift might be referred to the moraine epoch.

Its constitution is indeed somewhat unlike that of the moraine, but so far as the drift of the locality mentioned is concerned, these differences might conceivably be explained on the ground that the extreme marginal deposits of the ice, made during the time of its greatest and perhaps earliest advance, would be made up more largely than later deposits of materials already deeply weathered and disintegrated. The presence of occasional bowlders of fresh aspect in the extra-morainic drift of the region cited lends color to this view, though such bowlders are generally of non-decomposable material. On the other hand, this suggestion involves the difficulty that the marginal deposits of any ice-sheet, where the relationships are unequivocal, have nowhere been observed to be notably more weathered and decomposed than the material further back from the margin.

Within the general region designated above, it frequently happens that considerable bodies of drift occur at points more distant from the moraine, and that such areas are completely separated both from each other and from the moraine. Moreover, the isolated areas are sometimes situated so as to make it seem well-nigh or altogether certain that their separation is the result of the subaërial erosion which has taken place since the drift was deposited, indicating for the extra-morainic drift an amount, and therefore a period of erosion, much greater than that which has affected the moraine and the territory north of it.

More or less isolated areas of extra-morainic drift, sometimes large and sometimes small, occur just west of High Bridge,* exposed in railway cuts; just east of Pattenburg, likewise exposed in railway

* In my report for 1891, I did Professor Cook scant justice, in discussing the extra-morainic drift of New Jersey. I have since found that in his report for 1880 (p. 83), he refers to the drift at High Bridge and Pattenburg, although he did not interpret the drift as glacial. The report to which reference is here made has but just come into my possession.

cuts; two miles and more north and northwest of Somerville, exposed at various points along the road skirting the southwest face of the trap-ridge; at various points a few miles south of Rockaway, in the vicinity of Shongum, Union and Franklin; an area north of Mendham, both east and west of the village, best exposed at old quarries two miles or so south of west of the village, and in various gullies and excavations; in the vicinity of Bernardsville and Basking Ridge, exposed in railway cuts and pits (not all till-like); the four hundred and eighty-five-foot hill northwest of New Vernon (not till-like); an area two miles or so west and northwest of Liberty Corners (in part till-like); on Schooley's Mountain four miles south of Hackettstown (Kummel); south of Rockport, four miles southwest of Hackettstown; near Port Murray, especially south and southwest; a mile or so south of White House station (eight or nine miles north of west of Somerville) (Whitson); and two miles northwest of Pittstown (nine miles northwest of Flemington) (Whitson). Numerous other localities might be mentioned, but these will suffice for our present purpose. Some of these localities are nearly twenty miles from the moraine, while others are less distant.

There are other extensive areas of extra-morainic drift east of Phillipsburg, in the vicinity of Carpentersville, and thence northeastward to Washington, and at many points in this same general region; but the boundaries of these areas have not been defined. It is not yet known to what extent the various localities where it has been observed are connected, and to what extent they are isolated.

The areal distribution of this extra-morainic drift does not seem consistent with the hypothesis of its contemporaneity, or approximate contemporaneity with the moraine, whether it be the product of ice action directly, or whether it be the product of waters produced by the melting of the ice. No such general or widespread isolation of drift areas is known to occur within the area of last glacial drift in New Jersey or elsewhere. But because some areas of extra-morainic drift are not referable to the moraine epoch, it does not follow that none are. The possibility that some extra-morainic till is of last glacial age is distinctly recognized. This may very possibly be true of some of the drift immediately outside the moraine in the vicinity of Tabor, and perhaps elsewhere.

Topographic distribution of extra-morainic drift.—Again, the extra-morainic drift is sometimes found several hundred feet above

the moraine close at hand. This is true at various points south of Rockaway. The drift is not often found in great quantities at these elevations, but some of it is of very coarse materials. The same is true at various localities further west, in the region about Washington, Hackettstown and Phillipsburg. If this represent the work of the ice which made the moraine, the same must have advanced beyond the moraine with such strength as to override the elevations where the drift occurs. To do this would have required so great a thickness of ice outside the moraine that it must needs have advanced great distances on the lower lands between the elevations where the drift occurs. But of such extensions of the ice on the lower lands between the elevations on which the drift occurs, we find, in many localities, no evidence. On the other hand, the lower lands are, on the whole, less likely than the higher to possess the drift, though they must have been covered by more ice and for a longer period of time, if the drift be the product of the moraine-producing ice-sheet. The topographic distribution of much of this extra-morainic drift, therefore, does not seem to be explicable on the hypothesis of its formation by the sheet of ice which made the moraine.

It will be readily seen that the distribution of that part of the extra-morainic drift, which is higher than the moraine, is not referable to the waters of the last glacial epoch. Even if post-glacial warping of the surface be invoked, it could not explain the position of that extra-morainic drift which is higher, by hundreds of feet, than the moraine close at hand, if the former were the work of glacial waters operating during the moraine epoch.

Much of the extra-morainic drift antedates the last glacial epoch.—Some of the extra-morainic drift occurs in isolated patches which seem certainly to have been separated from each other by erosion subsequent to their deposition. Some of it lies at altitudes considerably above the immediately adjacent moraine, the intervening lower areas being free from drift. It would therefore seem that the geographic and topographic distribution of most of the extra-morainic drift does not leave open to doubt the conclusion that it was not deposited by the ice of the moraine-producing epoch, or by waters emanating from it. And since it does not seem possible that the drift could have originated since the last glacial epoch, it seems

certain that those parts of it which have the distribution above noted must be assigned to a date earlier than the last glacial epoch.

The occurrence of drift in the positions described would not be inconsistent with the hypothesis of its glacial origin during an epoch antedating that of the moraine, or with the hypothesis that it is residuary material resulting from rock decay. Neither is it inconsistent with the hypothesis that the drift is the product of aqueous agencies, operating at some time antecedent to the last glacial epoch. But if this be its origin, it must needs have been at a date antedating the glacial epoch by a very long interval of time, during which an enormous amount of erosion was accomplished and the topography profoundly altered thereby. On no other basis could its distribution be explained, if it be of aqueous origin. Between these various categories of drift it should be possible to decide.

The extra-morainic drift not residual material.—That the material which has been called drift is not residual, is so evident that the question does not need discussion. In most of the localities mentioned it contains many varieties of rock of very diverse origin, which could not have been furnished by any strata known to have covered the region where it occurs, or which can reasonably be supposed to have done so. The drift often covers those points from which, rather than to which, residual materials would have been moved. Its constituent materials are sometimes glacially striated, and the drift itself is sometimes distinctly stratified, both of which features would be impossible if the materials were residuary. This point may be passed without further remark, except to note that residuary materials which may bear some likeness to drift doubtless occur at various points. It is not these accumulations to which reference is here made.

Extra-morainic drift, in part at least, connected with an earlier ice epoch.—In the character of the extra-morainic drift we find inherent evidence that it is, in part at least, glacial. This is true, both of those parts which, so far as position is concerned, might belong to the moraine epoch, and of those parts which cannot. At the High Bridge, Pattenburg, Somerville, Shongum and Liberty Corners localities, and at various points about Hackettstown, Washington, Carpentersville, &c., glacially-striated materials have been found. They are abundant at some of these localities, though not at all. Some doubtful specimens only of striated stones were found near

Bernardsville, and none at Basking Ridge or New Vernon. The presence of glacially-striated materials at the various points mentioned indicates at least the proximity of ice when the deposits were made. The structure of the deposits is such as to indicate that water was not the sole agent of deposition. We must therefore ascribe them to glaciers or to berg ice.

Since the areal and topographical distribution of much of the drift containing glaciated stones forbids its reference to the last glacial epoch, we are led to believe that it had its origin during an earlier glacial epoch, whether it be the product of glaciers directly or of icebergs. Be it here understood that what is here said does not apply to all extra-morainic drift, but only to parts of it. Most of the drift near New Vernon and Basking Ridge, and some at other points, is not regarded as glacial, and locally some extra-morainic drift is perhaps to be connected with the moraine.

Further we find inherent evidence supporting the conclusion, based on its geographic and topographic distribution, that the extra-morainic drift cannot all be the work of the moraine-producing ice-sheet, and therefore that it represents, or that a part of it at least represents, the remnant of an older sheet of glacial or iceberg drift. This evidence is based on the chemical and physical condition of the drift itself. Its whole expression is that of age. It is deeply oxidized, both as regards intensity and distance from the surface. The rock fragments which compose it have been so far leached of their soluble constituents that many of them have crumbled to powder, or are ready to do so, so soon as subjected to movement or the least mechanical pressure. Many fragments which had little to lose by leaching have lost their integrity by the continued operation of the various processes of weathering. The hard sandstones and quartzites only have commonly preserved their integrity, and appear to be as solid as when first deposited in the drift. But even the quartzite and sandstone bowlders often show a surface alteration, which, though not of the nature of disintegration, testifies to their long exposure in their present form.

The changes here referred to are various. Two of the more obtrusive ones are surface changes of color and of hardness. The light-colored sandstones have commonly a thin surface layer which is essentially quartzitic in its nature. The restriction of this hardened portion to the surface of the stones clearly points to its production

subsequent to the time when the stone affected, assumed its present form. The change in color often accompanies the hardening. While the interior is whitish, or at least very light, the exterior is commonly darker in color, as if its iron content were greater or more highly oxidized. Since the coloration is on the exterior only, and concentric with the surface, it was probably produced after the stone had its present form. The purple sandstones, quartzites and conglomerates do not show the color change to so great an extent as the lighter sandstones, while the surface-hardening is also less commonly, and less perfectly developed. The surface changes here noted may not have developed entirely since the deposits now containing the stones exhibiting them were made. They may have affected the stones before they became a constituent of the drift. In some instances, at any rate, this is probably the fact. In this case they do not serve as an index of the age of the drift containing them. But apart from this particular, the physical and chemical condition of much of the extra-morainic glacial drift constitutes what we hold to be conclusive evidence of its great age.

It does not at all do away with the force of the point here made to urge that the material was deposited in a weathered and oxidized condition. In many instances it was demonstrably not so deposited, and the weathering is of later date. The evidence of this is the decomposed and fragile condition of masses and bits of rock which bear upon their outer surfaces indubitable evidences of rough mechanical action. The moraine and the drift area within it do not contain corresponding materials. The two types of drift, the morainic and intra-morainic on the one hand, and much of the extra-morainic on the other, are so radically unlike, physically and chemically, that it is not easy to avoid the recognition of their distinctness.

The constitution of the extra-morainic drift gives independent reason for believing that its origin is to be assigned to a date considerably antedating that of the moraine-forming ice-sheet. In many cases, it contains rock materials somewhat unlike those of the moraine and the drift north of it. The difference is often one of proportions, rather than of kind. Especially does this seem to be true of the abundant sandstone and quartzite constituents of the extra-morainic drift. Some of the bowlders and cobbles of these materials give evidence of having been in the form of bowlders and cobbles before they became a part of the glacial drift. Before they

became a part of the drift, they seem to have been part of a gravel formation, rather than part of a conglomerate, since they give no evidence of having been cemented together. A rational interpretation of these facts would seem to be that the gravel formation which contributed them was much more extensively developed when the earlier drift was deposited than when the later was formed. This would mean a long interval between the formation of the earlier and later drift-sheets, during which subaërial erosion removed much of the gravel, and of the drift of the earlier epoch.

Perhaps none of the facts mentioned are necessarily fatal to the hypothesis that the drift in question is the product of water accompanied by icebergs, originating from the ice of some earlier glacial epoch, rather than the product of the ice-sheet itself. Deposits of such a genesis might be as old as those made by the glacier ice of the same epoch, and might contain the same materials, in a similar physical and chemical condition. If this be the origin of the drift, it is necessary to suppose that very profound topographic changes have taken place since its deposition; more profound than it is necessary to suppose if glacier ice did the work directly, more profound than there is independent reason for believing have occurred. Furthermore, in the structure of some of the drift, there is direct evidence, in the absence of stratification in thick beds of drift containing glaciated stones and in the displacement of subjacent shales, that ice and not water was the agent of deposition. On the other hand, no striæ on bed rock have been found outside the moraine, and, in general, the extra-morainic surface escaped profound wear, or has since been so far altered as to obliterate its effects. The areas where striæ are most likely to be found have not yet been studied in detail, and future work may show them to be present. If topographic changes have been so great since the deposition of the drift as its distribution would seem to warrant us in believing, the time has been quite sufficient for the obliteration of any striæ which might have been made, except they were formed in positions and relations exceptionally favorable for their preservation.

The areal and topographical distribution of much of the extra-morainic drift, its physical and chemical condition, its physical and lithological constitution, its structure and relationships, point to a glacial origin, antedating by a long measure of time the drift whose approximate if not exact border is the terminal moraine.

It is not easy to see how the two types of drift can be mistaken the one for the other.

Scattered bowlders.—Apart from the areas where there is a considerable body of drift outside the moraine, scattered bowlders have a much wider distribution. In many cases they may be parts of a considerable bed of drift whose existence is not revealed because of lack of exposures. Erratic bowlders, which are drift of one sort or another (*i. e.* they are not indigenous), occur sparingly over a large area and within restricted areas at all altitudes. In the hilly and almost mountainous crystalline schist area southwest of Morristown, bowlders of sandstone and quartzite are present, though not abundantly, up to altitudes of more than 700 feet—that is, fully 300 feet higher than the moraine in the immediate vicinity. They have never been seen on the tops of the highest hills, but they have been seen on the summits of broader areas but little below them. It is doubtful if a square mile of the hilly region between the Great Swamp on the south and Dover on the north is altogether free from these bowlders, though they are so rare that they have not been seen on every square mile, even after all roads have been traversed, and frequently the territory between them. In the vicinity of Mount Freedom these foreign (drift) bowlders have been seen at elevations of nearly 1,000 feet, and a little further to the northeast, on summits more than 1,000 feet high, and more than 400 feet above the crest of the moraine at its nearest point, only three or four miles distant. At various points along the trap ridges, and between them, southwest of Chatham, isolated bowlders of gneiss and purple quartzite occur up to and on the crests of the ridges miles away from the moraine, and at heights considerably above it.

Although it is not affirmed that the drift in all the places mentioned is glacial, and it certainly is not all till, yet drift of one sort or another exists in all these places, and in all these places is to be accounted for. We are not now prepared to say to which of the several categories mentioned the drift of each locality belongs. But certain conclusions seem warranted, among them the following: (1) Some of the extra-morainic drift is the work of the water which accompanied the last ice-sheet. (Of this no mention is made in the foregoing pages, since there is no question involved in its origin about which students are not agreed.) (2) Some of the extra-morainic drift is glacial. (3) Much of the extra-morainic drift,

including some that contains glaciated material, and is therefore directly or indirectly indebted to ice-work for its origin, is so disposed and constituted as to make its reference to the moraine-making ice-sheet impossible; while (4) the origin of still other parts is a matter of doubt. Separate parts of it may fall into several of the various classes mentioned on page 60.

SECTION IV.

THE TERMINAL MORAINE.

The terminal moraine was located with approximate accuracy many years since by Professors Cook and Smock. Through their map, its position has become well known. Recent work has not materially modified the results which were reached by these geologists when glacial geology was in its infancy. The early map purported to give no more than the location of the outer border of the moraine, and not at all the inner border. The location of the inner border will be attempted on the maps now in preparation, but this limit must, of necessity, be more or less arbitrary at many points where the inner border of the moraine passes by imperceptible degrees into the ground moraine, or other phases of the drift lying within it. The representation of the inner border of the moraine upon the maps, thus defining the width of the moraine, will constitute the main change—or, perhaps better, the main addition—in the mapping of this part of the drift.

One other modification will also appear. When the moraine was first traced out and mapped, differentiation of the drift formations had gone less far than now, and the outer edge of the moraine was located along the line marking the limit of abundant drift manifestly connected with the great body of drift which lay to the north. Some of the material thus included in the moraine is to be referred to the work of water which carried drift beyond the border of the ice. In the new mapping, the outer border of the moraine belt will therefore be found a little inside the old position at a few points. This will be notably true in the vicinity of Morris Plains, and for some distance to the south, where thick beds of gravel lie outside the moraine proper, though making but a narrow border to it.*

Width of the moraine.—The width of the morainic belt varies

*It is worthy of note that, though Professors Cook and Smock had noted the existence of extra-morainic drift, they did not connect with the moraine anything which was not directly connected with it in time of origin. Even at the time they did their work on the drift, they recognized the fundamental difference in kind between the drift of the moraine and that without it.

greatly. In places it is but a fraction of a mile in width, while in others it is several times as wide. Not infrequently there are more or less detached areas of drift of morainic topography and constitution which are hardly to be connected with the main belt areally, but which are yet similar to it in constitution and topography, and probably also in origin. Such areas are not commonly far distant from the terminal moraine in position, and are really terminal morainic in their nature.

Composition of the terminal moraine.—On the whole, the terminal moraine is more gravelly and sandy in its composition than the ground moraine. This is doubtless the result of the co-operation of the water resulting from the melting of the ice. This would be more effective at the margin of the ice than elsewhere. It would here have freer opportunity than elsewhere to gather and carry away the fine materials, leaving the coarse, and it would here deposit much of the coarser part of the load which the ice had been able to carry to this point, either on or under itself. Much of the material included within the terminal morainic belt is, therefore, not the product prepared and deposited by the ice acting alone. It is not all morainic in the strictest sense of the term, though it is a part of the belt of drift accumulation marginal to the ice, and is, on this ground, included in the terminal morainic belt. Between Dover and Perth Amboy the morainic belt sometimes shows a large percentage of sand and gravel. This is particularly true of the stretch between Madison and Morris Plains, where sand or gravel pits have been opened at many points along the crest of the broad ridge regarded as the moraine. It is probable that the central mass of the ridge is often, if not always, of different material. But for one reason or another, water here seems to have modified the accumulation of drift marginal to the ice to a greater extent than in most places. Here we are within the area where the influence of Lake Passaic, if such a lake existed, would have been felt. On the other hand, the marginal accumulation of drift in the position of a terminal moraine may be largely of stratified material, as deposited by the ice and the waters issuing from the margin, even where no standing body of water was present. The abundance of stratified material between Madison and Morris Plains, along the line of the moraine, seems to be largely the result of original deposition, and not the result of subsequent modification by the water of any lake which may have existed.

Topography and topographic relations of the terminal moraine.— The topographic phases of the moraine are very various. In places it is very rough, hillocks and hollows or interrupted ridges and troughs following each other in rapid succession and tumultuous arrangement. Its relief is sometimes scores of feet within narrow geographic limits. The depressions inclosed by the elevations are frequently marked by marshes, ponds and lakelets, wherever the material constituting their bottoms is sufficiently impervious to retain the water falling and draining into them. These rough moraine features may be well seen along the line of the moraine east of Plainfield, especially from Oak Tree to Locust Grove.* Here its billowy surface, with its rapidly-shifting curves, its numerous hillocks and kettle-like hollows is so well developed as to make the surface fairly typical of strongly-developed terminal moraine topography. Where the moraine crosses the trap ridges near Summit, it has, locally, a strongly-accented topography, but the same is not continuous in its development. The moraine is again well developed, topographically, just east of Morristown, though not seen at its best along the high roads. In the vicinity of Rockaway, the morainic topography is locally strong (Peet). This is true two-thirds of a mile south of Mount Hope, and again a half mile north of Rockaway. North of Hackettstown, a mile north of Petersburg, and east of Townsbury (Kummel), the topography is also well displayed. It is also very rough at several points near Buttzville.

In other places the characteristic morainic features are more subdued, the billowy relief being far from bold. This is the general character of the belt throughout the stretch from the coast to Oak Tree. In other places the billowy topography is reduced to a minimum, or is even wanting. The latter condition of things is generally no more than local. In such situations the identification and mapping of the moraine is made largely on the basis of relations with other parts of the belt where the topography is more strongly and characteristically developed. Where the characteristic topography is wanting, the moraine is generally a belt where the drift is somewhat thicker than on either hand, and this thicker body of drift

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* See detailed topographic map of a small area of the terminal moraine southeast of Plainfield. Annual Report for 1891, p. 84.

often expresses itself as a low, unobtrusive swell or ridge, traceable on either hand into more typically-developed morainic tracts.

The morainic belt, as a whole, is sometimes a conspicuous topographic feature. It then stands up as a more or less distinct ridge, rising 50 or 100 feet or more above the country outside it, and, generally, to a less height above that within. True as this statement is, a false impression is likely to be conveyed by it unless it is given a moment's reflection. A ridge 100 feet high may seem sufficiently large to be obtrusive. But if the ridge be a mile wide, with symmetrical slopes, a height of 100 feet would mean a slope of 100 feet from the center to either margin, or a slope of 100 feet in a half mile. This would be a rise of less than one foot in twenty-five. This is by no means a steep slope, and a ridge of such dimensions and proportions would not be a particularly conspicuous topographic feature, unless its development were persistent and its course across a flat country. If the moraine have half the height and twice the width above indicated, and these are not uncommon dimensions, the slope would be greatly reduced. A rise of fifty feet per mile would mean less than one foot in one hundred, a rise which would be hardly noticeable, except in a region where the topography is nearly plane. The height of the moraine above its surroundings is not infrequently much less than the figure last named. It often crosses areas whose relief is much greater than its own height. It is, therefore, not always, perhaps not commonly, a conspicuous topographic feature.

It is important to keep in mind the distinction between (1) the moraine as a topographic feature, and (2) the topography of the moraine. As a topographic feature, the moraine is rarely conspicuous, except in plane regions, though locally it may be so, even in mountainous tracts. In the former case, it is frequently of importance enough to constitute a divide between small streams, and thus to be a factor in determining the course of drainage. In those parts of New Jersey where the country crossed by the moraine had a strong relief beforehand, the moraine has little influence in this respect. On the other hand, the topography of the moraine is frequently very pronounced, even where the moraine is not a conspicuous topographic feature. The topography of the moraine is as often sharply developed in regions of strong relief as in planer ones.

This relationship between preglacial topography on the one hand, and morainic topography and topographic conspicuousness of the

moraine on the other, is no accident. In plane regions the minor advances and recessions of the ice which every season tended to effect, were more easily accomplished. There were fewer and less effective obstacles offering resistance to ice-motion. Every terminal aggregation of material overridden by subsequent forward movements of the ice had its sharper features softened. The result was a tendency to the development of wide but continuous morainic belts with relatively smooth surfaces. In hilly and mountainous regions the ice movement was resisted by the elevations, and against them the terminal deposits were banked in a rough and forcible fashion, by ice whose movement was resisted. It is in such regions that the moraine topography is often roughest and most tumultuous. But it is also in such regions that the moraine's development is least regular. It is strongly developed only in patches, and as a relief feature is not commonly conspicuous. On the other hand, without greater thickness of drift and without being in any way more massive, moraines of plane regions are relatively more important, topographically, than those of regions of greater relief. It cannot be said, however, that any phase of moraine topography, or any degree of development of any phase of moraine topography, is confined to any particular topographic situation.

Not rarely the most conspicuous and obtrusive topographic features of terminal moraines are the work of waters accompanying the ice. The most sharply-marked hillocks are sometimes the kames, deposited by glacial waters marginal to the ice.

The moraine disposes itself instructively throughout the crystalline schist area. In the vicinity of Rockaway, for example, the position of the moraine, in relation to the elevations of gneiss, is such as to show that the ice pushed further south in the valleys between the elevations than upon the elevations themselves. The hills thus made re-entrants in the ice margin, and the drift was banked against them to greater heights on the north than on the remaining sides. While this is in perfect accord with the behavior of glacier ice in general, the vicinity of Rockaway is a locality where the resulting phenomena may be seen within narrow geographic limits. The extension of ice further southward in valleys than on the adjacent highlands is shown at other points. The southward bend in the course of the moraine where it crosses the Musconetcong, just above Hackettstown, is a case in point.

The terminal moraine as a site for residences.—The topography of the moraine is such as to make it an attractive site for residential purposes. In few regions has it yet been extensively utilized in this way, and its full possibilities in this direction have not yet been generally recognized. Its topography would not lend itself well to streets running with the points of the compass, or to straight streets running in any direction. But if this be a desideratum at all, it certainly is not the only one. The surface undulations often make winding ways of extreme beauty possible, and the eminences afford sightly locations for buildings. What may be done in this line is well shown by the attractive village of Short Hills. There are many other situations, as yet unimproved, which would make equally beautiful village sites, and will doubtless some day be utilized for this purpose.

Not rarely lakelets occur and add their charm to that of the unique moraine topography. In many situations where lakes do not exist, they could be developed and maintained at slight expense. The composition and slopes of the morainic belt are usually such as to afford good drainage, a consideration scarcely second to any other in the selection of building sites.

SECTION V.

ESKERS. OSARS.

Eskers had not been known to exist in New Jersey until the past summer. They were then found in several localities. Nowhere do they find better development than in the vicinity of Ramseys, in Bergen county. Prof. Culver, especially, has studied the eskers in this region. According to his interpretation, they constitute a somewhat complex system, beginning north of the State line. At various points in this region there are considerable areas of stratified drift, with which the eskers are associated, and of which they constitute a part. One narrow belt of stratified drift extends from the State line north of Mahwah, southward to Ramseys and beyond. Another about Allendale has an interrupted connection westward to Wyckoff. From this point a stratified drift area stretches north to a point two miles or so west of Ramseys. These areas of stratified drift are in or associated with valleys, and it is in connection with them that eskers find their best development, so far as yet known, within the limits of the State. Prof. Culver does not find the gravel and sand about Ramseys connecting westward with that north of Wyckoff, though the separation is not great.

According to his determination, an esker starts a mile or so east of Suffern, N. Y., runs nearly south toward Mahwah, but loses its distinctly ridge-like character in the gravel and sand area along and west of the railway in the vicinity of Mahwah. Just south of Mahwah the gravel belt has esker-feeders from the east, coming down the slope from the northeast, with greater disregard of topography than is the habit of the eskers of this region. Between Mahwah and Ramseys the eskers are interrupted, and large bodies of sand occupy a considerable portion of the valley. The gravels and sands are variously disposed. Great quantities of these materials not infrequently constitute flat-topped, delta-like bodies of small areal extent. In no case does Prof. Culver find an esker connecting directly with one of these delta-like bodies.

About a mile and a half north of Ramseys the main esker, which Prof. Culver regards as the continuation of the esker east of Suffern,

again becomes distinct. Starting just east of the railroad, its course runs south and then southwestward by a winding route. It crosses the railway in the north part of the village of Ramseys, whence its course is nearly southwest. It crosses the marshy tract southwest of the village, through which it constitutes a conspicuous ridge. Beyond the marsh it rises notably, but does not cross the till-covered ridge to the west. The 391 foot hill, shown on the topographic map, north-northeast of Ramseys, marks a high point of the esker. The esker has its most striking development southwest of the village, where it crosses the marsh. Here it stands up as a sharp, almost wall-like ridge, having a height of about twenty-five feet. Its crest is often no more than ten feet or fifteen feet in width, and nearly horizontal for considerable stretches. From this narrow crest the slopes fall off abruptly to the low land on either side, the angle of the slope being often as high as the looseness of the material will permit. Its real character, as well as the ideal character of an esker, is best appreciated by walking southwest along its summit for a quarter of a mile, beginning at a point a little more than a half mile southwest of the station at Ramseys, at the point where the high road leading from Ramseys descends from the ridge. (Plate I.) Near Ramseys, esker branches are given off to the southward, but they do not continue for any great distance. The position of this esker, as well as the position of many of those mentioned in the following pages, is shown on the accompanying map opposite this page. (Plate II.)

Another well-defined esker begins about two miles northwest of Ramseys station, just west of the brook, and has a south-southwest course for three miles. The roadway between Ramseys and Darlington cuts squarely through the esker, showing it to be composed of coarse gravel which is more than usually compact for esker gravel. This esker is twice interrupted in its course by narrow stream gaps. These gaps, as most of those of this region, are clean cut. The gravel which might have filled the notches is absent, and not strewn about the surface in the vicinity of the gaps. The esker ridge on either hand approaches the gap after the fashion of a railway embankment, where the track is to cross a creek on a high bridge. Like the artificial grade, the esker embankment descends from higher land on either side, and is continued out into the valley. Toward the stream it stops abruptly on either side, just as if awaiting a bridge to span the interval. The southern terminus of this esker

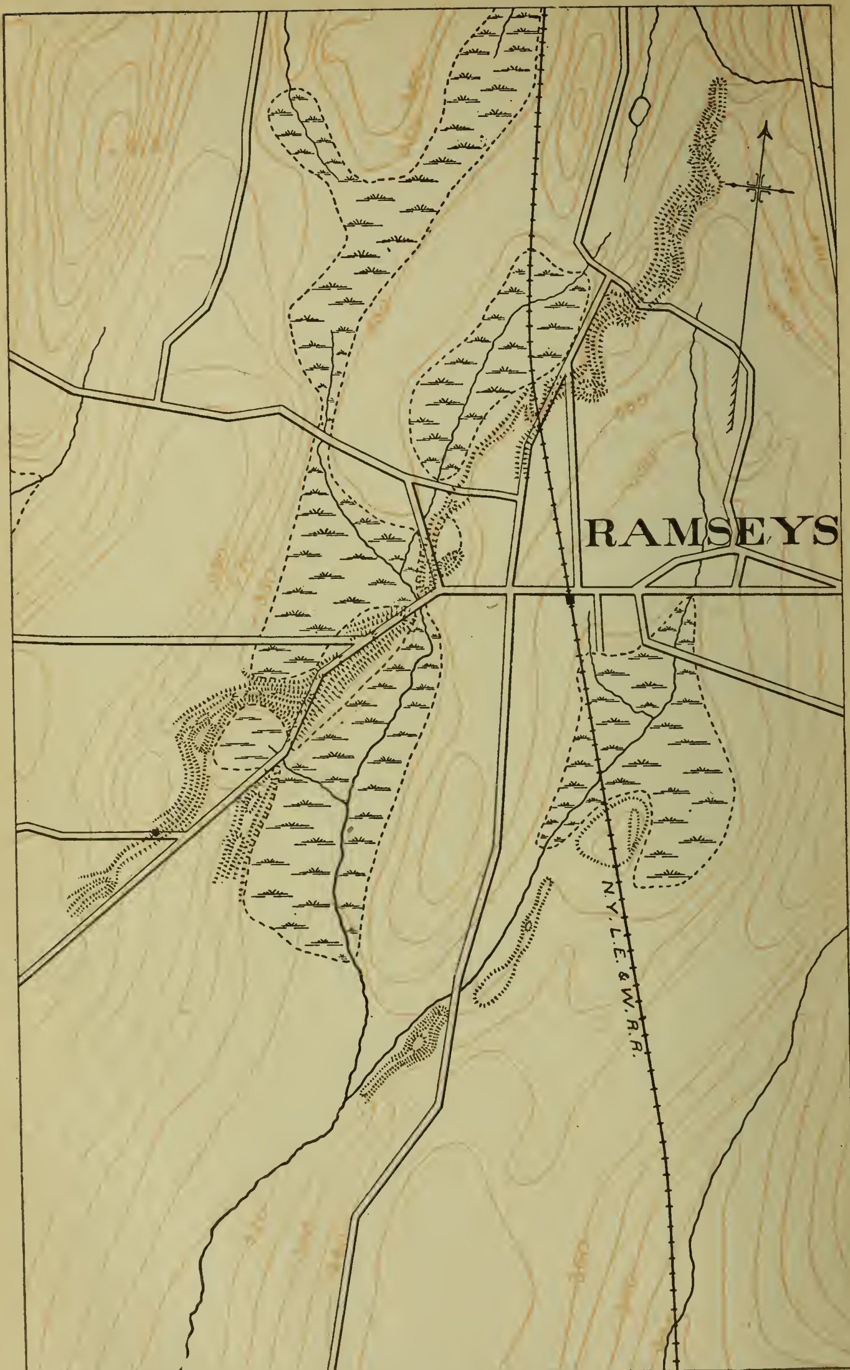

PLATE I.—Eskers at Ramseys, Bergen County.

Plate II.

Map of
ESKERS, near RAMSEY'S
BERGEN COUNTY
Scale 1 inch to a mile

is abrupt at a point nearly three miles north of Wyckoff. A second esker parallel to its southern end lies a quarter of a mile west of it. Both connect with a gravel-and-sand tract which leads down to the railway between Wyckoff and Camp Gaw. Descending into this gravel area from the north and northwest are other esker ridges in the line of the continuation of the Ramseys eskers, with which, however, Prof. Culver does not connect them.

North of Allendale, a half mile or so, an esker takes is source, and runs, in a general way, southwestward. Though not without interruptions, it can be traced to the gravel area northwest of Wyckoff. At this point the gravel area has a kame-like aspect, but is not without esker-like ridges, especially to the east.

In the swampy area, a half mile or more south and a little east of Ramseys, begins an esker which has a length of about a mile, its course being nearly due southwest. It is ten or fifteen feet high, and is well defined. Its course is parallel to that of the little creek lying west of it. It terminates abruptly where this creek joins the creek coming south of the marsh west of Ramseys.

A quarter of a mile further southwest, across the united stream and nearly in line of the esker just noted, there appears to be a point of junction of three short eskers. A branch from the Ramseys esker makes toward this juncture, but it dies out before reaching it. About this junction one short esker ridge comes in from a direction north of east. Another leads off to the south, while a third comes in (or leads off) from the west-southwest. The esker leading southward from the above junction unites with the Allendale esker a mile and a half west of Allendale station, through one of the peculiar gravel areas, of which there are several in the region, and which are manifestly part and parcel of the esker system.

Another esker, more than a mile long, has a north and south course, running south from Rochelle Park, near the New York, Susquehanna and Western railway. Its position is low on the west slope of the Saddle river valley. It is a low, irregular, gravel ridge, rarely more than ten or fifteen feet in height, but still well defined through most of its course, and notable for its extremely gravelly constitution.

In none of these places do the eskers occur predominantly on high lands; they are either in valley bottoms or low down on valley slopes. While in the details of their courses they exhibit some slight

degree of independence of topographic details, they yet seem to be, in general, dependent on pre-existing topographic features. Their topographic distribution strongly suggests a subglacial rather than a superglacial origin. They have not yet been studied with this point in view with sufficient care to warrant a positive assertion on this point. But in general the eskers do not appear to be sunk into the surface over which they wind. In some cases they are seen to rest on till, as if no eroding action had preceded their deposition.

Near West Livingston, a short esker has a northeast and southwest course. A low gravel and sand hill in the midst of a marsh about three and a half miles southwest of Livingston, and a short distance west of Washington Place, may, perhaps, be looked upon as its extreme southern end (Kummel). It is interrupted by the alluvial plain to the northeast toward Cheapside, but is continued beyond as a low gravel ridge, breaking up into two rather sharp knolls at Cheapside. From Cheapside to West Livingston, the esker continues as a distinct winding ridge, but with no sharp curves. No exposures occur, but the surface indicates the sand and gravel composition of the ridge. About half way between Cheapside and West Livingston the crest of the ridge is marked by depressions. Northeast of West Livingston the ridge becomes more prominent, and where it crosses the road between Livingston and West Livingston, a half mile from the latter place, it is well defined, being twenty feet in height and composed of coarse gravel. Further north, the ridge becomes less prominent and finally ends in a sharp knoll fifteen or twenty feet in height. From this termination a small area of sand stretches to the northeast. Between Cheapside and West Livingston the esker is bordered on the west by a narrow area of gravel, the topography of which is somewhat undulatory. The entire length of the esker, with its windings, is something more than two miles. Its height varies from a few feet (four or five) to something more than twenty. This esker, as well as the following one, was located by Mr. C. E. Peet.

Another short esker has an east-west course in the forest between Milltown and Connecticut Farms. This ridge is low, but well defined, and has the windings characteristic of such ridges. Traced from east to west, it commences about one mile west of Union (Connecticut Farms). Here it rises up from rather flat surroundings in the form of a low, but well-defined ridge. It has a winding course,

running westward, for about one-third of a mile, with a height of about ten feet. It is here interrupted, but is continued to the westward a little further on as a distinct ridge twelve to twenty feet in height, and about one hundred feet in width. In a general way, its height is greater where its width is less, and *vice versa*. Toward its western end the esker becomes notably sinuous. After a course of about a mile, it is lost in the gently-undulatory gravel plain. The material of which it is composed varies from coarse gravel to fine sand. The western end has an abundant scattering of bowlders and bowlderets of considerable variety. Nowhere does this esker cross any highway, nor is it anywhere distinctly seen from any road.

A much longer and more massive esker, though much interrupted in its course and often less clearly defined, runs through Afton, Morris county. Its southern end is one and a half miles northeast of Madison. For a mile or so, it lies about one-third of a mile east of the Madison-Afton road. Pursuing a north-northeast course, it crosses the two roads running southeastward from Afton, and holding the same general direction, it lies just east of the road running from Afton to Hanover. After a slight interruption north of the church at Hanover, it continues three-fourths of a mile further north. The total length of the esker is about three and one-half miles. There are ten gravel and sand pits along its course in this distance, and the gravel and sand associated with the esker have often something of the kame disposition. Nowhere does the esker have distinct branches which persist for more than a few rods, though at some points seeming branches break up into kame-like hillocks. Its crest is uneven, often rising into somewhat sharply-marked hillocks. But ever and anon it develops the narrow ridge-like character which is so characteristic of the type with which it is here classed.

It is altogether probable that other eskers will be found in the Highland region of the State when the whole area is carefully studied. More careful study of the composition and surroundings of the eskers is necessary in order to make all points concerning their history satisfactorily clear. But that most of those now known are the work of subglacial streams seems to be indicated by their distribution, compositions and relations. No critical discussion of this point will be essayed until all the eskers of the State have been studied, when the whole system will be discussed with reference to genesis. Further work on the eskers will be in progress by the time these pages are through the press.

SECTION VI.

KAMES.

Kames were not differentiated from other types of drift when the glacier deposits of New Jersey first attracted attention some years since. More recently, kames have been found to be very abundant in various parts of the State. They sometimes occur as isolated hillocks, and sometimes in groups. In either case the type character may be well developed. Less commonly there are considerable areas of sand and gravel whose surfaces are markedly undulatory, though the elevations are low and not clearly separated from each other. Such areas may be designated *kame areas*, since the hillocks are not sufficiently differentiated to separately merit the designation kames. The kames which are now known in New Jersey are so numerous as to make separate mention of all inadvisable in this report. They are of frequent occurrence throughout much of the lower land of Bergen county, and in the eastern part of Passaic, and are not rare in any of the lower areas of drift thus far studied. Typical kames may be seen at many points. Those which are here mentioned will serve for illustrations of the type. The first five here mentioned were located by Mr. Peet.

1. One mile northeast of Little Falls, on the south side of the Passaic river, a typical kame rises twenty-two feet above the plain, with an altitude 162 feet above tide. It is composed of sand well exposed in a pit. Below a thin surface layer, which has probably lost its structure through the operation of surface agencies, the stratification is distinct. The kame has regular, smooth slopes, and its longest diameter is but little greater than its shortest.

2. One-fourth of a mile east of the above kame, near the trap ridge, is another kame well exposed at its west end. The contour lines of the topographic map define its shape. Its southern slope is steep and its northern more gentle. At the exposure, there is about three feet of till-like material containing striated stones. On the top of the kame are bowlders, the largest of which are about three feet in diameter. One granite bowlder seven feet in diameter lies at the base

of the hill near the excavation. The till-like material seen at the exposure does not cover the entire kame. The exposure shows several feet of stratified sand, occasional seams of which are cemented by iron oxide. Interstratified with the sand are occasional seams of clay showing fine lamination. At its east end, the kame is made up of stratified sand and fine gravel, and wraps around a boss of trap rock.

3. Just north of the kame last noted is another connected with it by stratified drift, but separated from it by its topography, as the contour lines of the topographic map show. It has smooth, regular slopes on the southeast and southwest sides. On the north and northeast it is undulatory as far north as the brook, where trap outcrops. The eastern limit, as indicated by the topography, is near the two hundred and sixty-foot line, but the sand and gravel extend a little further. The constitution of this kame is well shown at its west end. Fine sand makes up 95 per cent of its mass. Of the gravel, something like 60 per cent is red sandstone and fine conglomerate, about 20 per cent granite and gneiss, and 10 per cent trap. Greywacke, quartz, &c., constitute the small residuum. Some of the pebbles are one and one half inches in diameter, but most of them are less than half this size. A granite bowlder six feet by eight feet by five feet lies at the west end of the kame.

4. About four miles west of Little Falls, between Fairfield and Clinton, are two well-defined kames. They rise thirty-three feet and thirty-eight feet, respectively, above their gently-undulatory surroundings. The higher hill (208 feet above tide) stands out as a conspicuous topographic feature. It has regular contours, but its constitution is nowhere well exposed. Its surface bears a few bowlders. The lower kame (the two hundred and three-foot hill) is one-third of a mile east of the other. It is equally prominent, but has not the same regular contours. A gravel pit in the southeastern side shows it to be composed of coarse gravel.

5. About one and a half miles west of Haledon, just north of West Paterson, on the road toward Pequanac, are two remarkable kames. They rise up twenty feet or more above the plain to the west, and are prominent features in the landscape. They are remarkable for the sharpness of their outlines and the steepness of their slopes. Their surfaces are regular and the angle of their slopes high. Bowlders occur on the surface of both kames. The surface material of the westernmost kame is fine gravel, ranging up to three inches in

diameter. In the other kame a few yards east a pit has been opened, and the exposure reveals stratified gravel. Pebbles three to four inches in diameter are common, but larger stones, including bowlders, are not wanting. With these two kames is associated a third, a little further south, though all three are sufficiently distinct to be regarded as individual kames. The last-mentioned kame consists not of one hillock alone, but of several minor hillocks with depressions between. Bowlders occur on its sand and gravel surface. It ends in a flat bench at the three hundred and forty-foot level—the level of the gravel plain north of Preakness.

6. Another well-defined kame occurs in the western part of the city of Rahway. The forty-two-foot hill of the topographic map marks its position. It is well exposed in several pits opened for the gravel and sand of which it is composed.

KAME AREAS.

In many places sand and gravel areas of great or small extent possess a markedly undulatory topography. The knolls have the form of kames, but are often only partially separated from each other. Such areas of stratified drift, where kame-like hillocks are numerous and closely associated, often joining each other, are designated *kame areas*. Kame areas are, on the whole, more likely to occur on low land than on high. Locally they are distinctly restricted to valleys and low plains, their borders being coincident with the borders of the low land.

The Rockaway valley and Green Village kame areas.—Kame areas of peculiar development and relations have considerable extent in the valley of the Rockaway river, between Montville and Hanover Neck, and again southwest of Madison, in the direction of Green Village and beyond. The two areas are mentioned in the same connection since they have much in common. In the latter situation the kame area is anomalous in position, in that it lies altogether outside the terminal moraine, and altogether beyond the limit certainly known to have been reached by the ice of the last ice epoch. The adjacent moraine in the vicinity of Madison is itself largely composed of kames. From the moraine, the kame area stretches off to the southwest, covering the northeastern part of the low, flat area of stratified drift which covers the Great Swamp and some surrounding territory. This strati-

fied drift is of glacial age but of aqueous origin, though there is much in its surface appearance to suggest that the roughness of topography is due to the wind. The undulatory surface here becomes most strongly marked near the moraine, and gentler and gentler with increasing distance from it. The diminution in roughness is accompanied by a diminution in coarseness of the material. Near the moraine, sand and fine gravel predominate. But the sand is in excess of the gravel, which presently almost wholly disappears. The sand quickly becomes finer and passes into silt. The disappearance of the sand is coincident with the disappearance of the undulatoriness of the surface.

In the Rockaway valley, the kames lie within the terminal moraine and occupy the bottom of the valley *even down to the present flood plain of the river.* Since they were made, the river seems not to have lowered its channel by any considerable amount. The Rockaway valley kame area begins just east of the point where the river turns to the south, two miles northeast of Old Boonton. Its development is here weak. The kame-like character is better shown a little further south, along the road leading in a westerly direction from Horse Neck bridge. The hillocks are confined to a belt about half a mile wide on the east side of the river. West of the Horse Neck bridge, the kame-like hillocks have a tendency to elongation in a north-south direction. Where the river bears to the east, northwest of Pine Brook, the kame-belt preserves its north-south course, and appears on the west side of the river. The topography is here striking. While the hillocks are not high, or the intervening hollows deep, both are clearly defined and follow each other in quick succession. The depressions are frequently occupied by ponds or peat-bogs. Throughout the area, the kames are, on the whole, small. Many of them are mere mounds, no more than five feet or ten feet in height. The depressions are, locally, as striking as the hillocks. In constitution, the surface material, at least, is predominantly sand. With it is associated fine gravel, the pebbles rarely being an inch in diameter, but they are frequently more than half that size, and apparently too large to be referable to the wind. Bowlders are, for the most part, wanting, as are also cobble-stones.

Northeast of Pine Brook, on the southeast border of the Great Piece Meadows between Clinton and Fairfield, the surface presents, in subdued form, many of the same characteristics as those of the area just described, but the depressions are here quite as marked as

the hillocks. Here, too, fine sand predominates, but small pebbles are occasionally found. The undulations of the surface are, perhaps, too gentle to allow the area to be characterized as a kame area, but contrasted with the area along the Rockaway, its differences are differences of degree and not of kind. In both regions the areas under consideration are low, scarcely above the river level, and they are in such close proximity as to make their mention in the same connection seem proper.

Some minor developments of similar features occur in the valley of the Passaic above New Providence. The development is here less extensive and the hillocks more isolated.

No satisfactory explanation of these remarkable kame areas has suggested itself. They are all along low drainage lines and are manifestly connected with glacial drainage, but the exact mode of their origin seems to be somewhat different from that of typical kames. Perhaps their relationship is with pitted plains rather than with normal kames. This seems to be especially true of the kame area southwest of Madison.

The absence of strictly glacier-deposited material from the surface parts of the kame area of the Rockaway valley seems to indicate clearly that glacier ice, or, at any rate, that active glacier ice, had entirely withdrawn from the valley at this point before the kames were made. The fact that they were neither worn away nor buried seems to indicate that no great body of glacial waters poured through the valley subsequent to their formation, since the passage of a flooded stream would have accomplished either one result or the other. On the other hand, the explanation of their topography seems to require at least the passive assistance of ice, though perhaps not of strictly glacier ice.

With the origin of these kames are associated a number of questions which are not yet solved. The solution of the problem of the glacial drainage of the area bounded by the trap ridges on the southeast and by the crystalline schist area on the northwest, has not yet been worked out. With this drainage, after the ice had receded from the position of the terminal moraine, the Rockaway valley kame area seems clearly to be associated. But this does not explain the method of its development. Its position on low land and in the lee of a trap ridge is perhaps significant. This is a situation in which ice would be likely to become stagnant during the dissolution of the ice-sheet,

and stagnant ice may very possibly have been passively concerned in the development of the kames. It is conceivable that at a certain stage in the history of the glacial epoch, drainage from the Horse Neck ridge above might have brought down sand and gravel, spreading it out on the stagnant ice surface in the lee of the trap ridge. Upon the melting of the ice such sand and gravel might assume the disposition now possessed by the Rockaway valley kame area. If this were the true explanation, there should be found on the west face of the ridge indications of the lines along which the sand was carried down, if the transportation took place after the western slope of the ridge was free of ice. These have not been found. If the drainage which carried down the sand was on the surface of the ice, before the slope of the trap ridge was laid bare, the lines of transport would perhaps not be traceable at the present time.

Through the Rockaway valley, considerable streams of glacial water from the north must have coursed, after the ice had receded a considerable distance beyond the valley where the kames occur. The deposits of these waters might have been made along the edges of the stagnant ice, or even on its surface, if circumstances were favorable. The melting of the ice might have allowed its covering to assume the irregular topography which now exists. The drainage through the valley from the north, together with the presence of stagnant ice in the valley, may have afforded the conditions for the development of the kame area in the valley. If these be the conditions under which the kame-like topography of the area was produced, it may be an open question whether the region affected should be called a kame area. If the explanation be sought along this line, we must suppose that the ice, on or along which the sand was deposited, did not entirely disappear until after the valley had ceased to be an avenue of active glacial discharge. Otherwise the kame-like hillocks would have been buried or demolished, for that they could have persisted for any length of time without destruction or burial along an avenue of glacial drainage, seems incredible.

A similar explanation might be equally applicable to the area of similar character which lies between Two Bridges and Clinton, southwest of Little Falls, though within this area there are some well-developed individual kames. These, however, may well antedate the development of the broader sand area of less relief about them, which is, perhaps, as closely allied to a pitted plain as to a kame area.

But the same explanation hardly seems applicable to the region about Green Village, southwest of Madison, since this lies altogether outside the moraine. It is, of course, possible that the ice in the last ice epoch extended beyond the moraine. It would seem highly probable, too, that a very considerable body of water must have occupied the area of the great swamp when the ice stood at Madison. The kame area occupies that side of the site of this probable body of water which was nearest the moraine. Into the water considerable discharges of ice may have been made. If there were grounded blocks of ice, or blocks of ice weighted down by drift, or stagnant ice, in the east end of the Great Swamp area, the deposits of drainage vigorous enough to carry sand and spread it over or among the ice would seem to supply conditions under which the undulatory surface might have originated. But there are difficulties in the way of accounting for the presence of the ice in the situation necessary. The region beyond (southwest) of the kame area is covered to considerable depths by deposits of loam and clay of lacustrine origin. Into this the kame area grades, both as regards its topography and material. If information derived from wells dug long since may be relied upon, the same clay lies beneath the kame area. If this be true, the sand must be assigned to a late date in the history of the body of water which occupied the Great Swamp.

No explanation of these kame-like accumulations, which seems at all adequate, has suggested itself. It is hard to see how the sand could have attained its present disposition without, at least, the passive aid of ice, and it is difficult to see how a sufficient body of ice could have been present. It may be that the area is to be regarded as nothing more than a pitted plain or an unusual form of overwash. In any case, its topography needs explanation.

Among other kame areas, the following may be mentioned:

The Montville kame area.—East of Montville and south of the Delaware, Lackawanna and Western railway is a well-developed area of kames. The more or less separate kames are high and conspicuous. They are composed of gravel and sand, well exposed in numerous pits. Bowlders are not wanting. Much of the gravel is well rounded. These kames lie just north of the Rockaway valley kame area, and may, perhaps, be looked upon as the northern terminus of the same, or, perhaps better, as their head.

The Boonton kames.—A little less than a mile due south of Boon-

ton station there is a well-developed clump of kames, which illustrates the type as well as any single area. As a type, this area has the advantage of being readily accessible. The topography and general habit of the kames is well seen east of the railway, and south of the east-west high road, where it is joined by the north-northwest road leading southward from Powerville.

Bloomfield kame area (Peet).—About one-half mile west of the Delaware, Lackawanna and Western railway station at Bloomfield there is a group of kames, well exposed at numerous sand pits. A coating of two to ten feet of unstratified drift covers the stratified gravel and sand, which has the structure characteristic of kames. The Bloomfield kame area is limited on the north by till, but on the northeast and southwest by gravel. The gravel to the southwest extends along the valley of the east branch of the Rahway river, finally uniting with the gravel plain at Springfield. Upon the surface of this long, narrow belt of gravel, well-marked kames are occasionally developed. One mile north-northwest of Orange station, in the midst of this belt, a cemetery marks the site where kames have a distinct local development.

From a point a little north of Highland avenue, southward along the valley to Maplewood, numerous kames occur. Many of them have a thin coating of unstratified, till-like drift. They are mainly composed of coarse gravel and sand. Many of the kames are altogether separate, and have oval shapes with smooth contours. At Orange Valley, an exposure in a single kame on the left bank of the river reveals its structure. A coating of yellow loam two to three feet deep, overlies three feet of coarse unstratified or indistinctly-stratified gravel, which, in turn, covers six to eight feet of gravel showing distinct cross-stratification.

Verona kame area (Peet).—From about one mile south-southwest of Verona, two or three miles west of Montclair, a gravel area extends northeast as far as Cedar Grove. It is often loam-covered. The Caldwell railway between Verona and Cedar Grove furnishes good exposures. Numerous sand pits give good sections along the road from Cedar Grove southwest to Verona, along the west bank of Peckman's brook. The kame topography is well shown about half way between Cedar Grove and Verona station, and again about three-fourths of a mile southwest of Verona station, on the west bank of the brook, where numerous exposures and sand pits show typical kame

structure. About half way between Cedar Grove and Verona station a sand pit on the west side of the road, opposite the gold-dust factory, gives a section which, in 1892, showed distinct faulting. The material of this area is various. Just south of Verona station it is mainly of coarse trap gravel, overlain by yellow loam to the depth of two or three feet. The railway cuts sometimes show the stratified materials to be somewhat mingled with the till.

Caldwell kame area (Peet).—Commencing about a mile north of Caldwell, a gravel area about a mile in width runs southwestward for four miles and more, passing through Essex Fells, Rowland and Livingston. Within this area are many kames, several limited gravel plains and considerable stretches of gravel and sand which belong to neither the one category nor the other. Throughout the area there is a somewhat discontinuous mantle of loam, which is often sufficient to afford a productive soil. The portions of this tract which belong to the kame-area category are to be found (1) a half mile and more west and southwest of Caldwell, and (2) in Livingston, and east and northeast of the same. In both these regions the kames are fairly well developed. Near Livingston marked depressions accompany the kames. Good exposures occur one-fourth of a mile east of Livingston, one-fourth of a mile or less west of Caldwell, two-thirds of a mile southwest of Caldwell, in the east bank of the brook, and a half mile from Caldwell on the road to Essex Fells. In these exposures the stratification is often seen to be distinct, more or less crossed, and sometimes faulted.

The Totowa kame area (Peet).—The two hundred and twenty-seven-foot hill at Totowa, two and a half miles northeast of Little Falls, is a kame, connecting to the southward with other kames. Together they constitute an area about one square mile in extent, but somewhat longer from north to south than from east to west. The area runs east as far as the Passaic terrace, and south to the Passaic river. Along the south border, the Delaware, Lackawanna and Western railway cuts through the kames, exposing fine sections. The exposure in the two hundred and twenty-five-foot hill, as marked on the topographic map, shows about twenty feet of fine stratified sand, covering an equal thickness of interstratified gravel and sand.

Kames northeast of Pequanac (Peet).—One and one-half miles northeast of Pequanac, Passaic county, and at the head of the brook which empties into the Pompton river at Mountain View, there is a

small area of kames. The hillocks and ridges are often distinct, rising up sharply from their surroundings and extending in a general west and southwest direction. The material of the surface is loose gravel and sand. Bowlders are not rare. At the south end of the area a gravel pit shows the material to be subangular gravel with a sandy matrix. Above the gravel is a coating of earthy loam, in which a few pebbles occur.

Kames southwest of Westwood (Culver).—Another well-developed area of kames is situated two and a half miles southwest of Westwood, and an equal distance northwest by west from Oradell, Bergen county. The area is less than a mile in greatest diameter, but it is characteristically rough. In constitution this kame area is more sandy than most of those of northeastern New Jersey. The topography is well delineated on the contour maps.

The Hohokus kame area (Culver).—Another kame area lies a mile or so northeast of Hohokus, Bergen county. In topography it is much like the preceding, but in constitution it is much more gravelly. On the east, this area descends to the level of the Saddle river. The relation of the kame area to the river and to the high land on the east bank of the river affords one of the many evidences of lack of any considerable erosion since the last occupancy of the valley by ice.

The Demarest kames (Culver).—A half mile east of Demarest station, Bergen county, lies the south end of a group of kames which extends three-fourths of a mile north-northeast. The topography here is markedly morainic. Both knobs and kettles are conspicuous, the latter in one or two cases reaching a depth of fifty feet. Short as the kame belt is, its length is much greater than its width, and its greatest extension is approximately at right angles to the direction of ice movement. The surface and form of the area are such as to strongly suggest its relationship to a terminal moraine. It seems highly probable that these kames were developed at the immediate margin of the ice, and that the roughness of the terminal moraine belt, at some points, is due to a like activity of the same agents, working under similar conditions. Occasional bowlders occur on the surface of the kames.

Rivervale kame area. (*Kame moraine.*)—The most unique and most striking group of kames which has thus far been seen, occurs less than a mile northeast of Rivervale, Bergen county. This area has, roughly, the form of an open horseshoe with ends bent outward,

its convexity facing the southwest. Its total length is almost one and three-fourths miles, and its width, except at the northwest end, less than one-fourth mile. The form, the topography and the topographic relations of the belt are such as to remind one strongly of a terminal moraine. It is characterized by high, knob-like hills, one remarkable kettle, and many lesser ones. Till fills the concavity of the curve, coming up sharply to the kame belt, and from its outer side a gravel-and-sand plain stretches off to the south, after the fashion of an overwash plain. In its relations to other phases of drift, therefore, as well as in the particulars already specified, the kame belt stands in the position of a moraine. For it, and for similar aggregations of kames, the designation *kame moraine* is proposed.

To the same category belongs the interrupted belt extending from a point just north of Westfield to Waverly, and best developed two miles northeast of Cranford. Although this belt frequently contains hillocks of till, and though till is sometimes exposed beneath gravel and sand, yet sand and gravel, disposed in the manner of kames, is the conspicuous portion of the belt.

The West Norwood kames (Culver).—Between West Norwood and Randell, Bergen county, just east of the West Shore railway, there is a long, almost esker-like ridge, which is broken up into a series of hillocks resembling kames. The general form of the area is that characteristic of an esker, rather than characteristic of a kame area. The topography, on the other hand, is more like that of a kame tract.

The Wyckoff kame area (Culver).—Commencing a half mile northwest of Wyckoff, Bergen county, and extending thence northeast and northwest, there is an area of gravel and sand which freqently has a marked disposition to develop into kames. The gravel here is closely associated with a series of eskers, and the two types, though clearly enough marked in individual instances, so completely grade into each other at many points as to render their classification difficult. Much more of the area, which includes only about a square mile, has a kame-like, than an esker-like disposition.

The Franklin Lake kame area (Culver).—North of Franklin lake, Bergen county, and beginning at its shore, is an irregular kame area, whose topography is somewhat rough and decidedly morainic in general aspect. The area stretches off to the northward for about a mile and a half.

Newark kames.—In this connection should perhaps be mentioned

an area just north of Newark, along the right bank of the Passaic, from Belleville to Riverside. This is not a typical kame area, though the surface has something of a kame habit. The material is much coarser than that characteristic of kames, and the topography of the drift at this point, as well as its constitution, suggests moraine affinities. Certain features of the drift on the opposite side of the river, at Harrison, as well as certain features northwest of Belleville in the direction of Watchung, suggest that this is a line which marked the position of the ice-edge during its retreat, for a time sufficiently long for marginal accumulations of moraine-like and kame-like affinities to attain a recognizable development. The material of this accumulation is well shown in pits and cuts at Riverside, Woodside and North Newark. The topography finds its most kame and moraine-like habit in the same region. To the southward, this area of rough topography flattens out to a plain of finer gravel and sand, having somewhat the aspects and relations of overwash. This is true on both sides of the Passaic.

SECTION VII.

OVERWASH PLAINS AND VALLEY TRAINS.

Overwash plains and valley trains possess much significance and importance in various ways. The steepness of slope and the coarseness or fineness of the material composing them give evidence of the vigor of the drainage, and therefore of the attitude of the region where they occur when they were formed. Where the material is coarse, the depositing waters must have been swift; where it is fine, slow. It is true that volume of water, as well as slope, is a factor determining velocity, but after due allowance is made for effect of volume, it is still possible to reach a tolerably definite conclusion concerning the attitude and therefore the relative altitude of the land when the overwash was deposited. Even great volume of water cannot produce strong currents without a certain minimum of slope. Coarse deposits which skirt the moraine in a narrow belt only, grading off promptly into fine, indicate a more moderate movement of the depositing waters than do coarse deposits which form a wider belt extending greater distances from the moraine. Where all the overwash deposits bordering the moraine on the outer face are fine, even up to the moraine itself, it is evident that the conditions of drainage were such as to produce slow currents only. Most of the overwash plains and valley trains in New Jersey are of material sufficiently coarse to indicate that drainage was measurably vigorous during the moraine-forming stage of the glacial epoch. The currents must have had some such strength as the present rivers in times of floods.

OVERWASH PLAINS.

The name overwash plain expresses the fact that the topography of the formation under consideration is, in a general way, plane. But in detail the overwash plains are sometimes far from flat. They are rarely marked by elevations of much size, though swells five to ten feet in height are not uncommon near the moraine edge of the plain. On the other hand, overwash plains sometimes grade into pitted plains, the pits or depressions being shallow and saucer-shaped, or

now and then much steeper and kettle-like. The depressions are in size and shape the counterpart of the elevations just noted, but are on the whole of more frequent occurrence and of larger dimensions.

Elevations of another sort sometimes project above the overwash sand and gravel of the last ice epoch. These are hills, large or small, which the glacial waters did not cover and therefore did not bury. They are surrounded by the sand and gravel deposited by waters issuing from the ice. The sand and gravel may wrap about their bases, but fail, by various amounts, to reach their tops. Such elevations may be regarded as islands of greater age in the youthful overwash plains, but they are not constituent parts of such plains.

Overwash plains are composed mainly of gravel and sand. They are often coated with a sandy loam, representing the last phase of overwash deposition, when the waters had been so far reduced in volume or their source so far removed as to make them incompetent to carry coarse material. There is a common impression that because overwash plains are made of gravel and sand, they must of necessity be sterile and unattractive regions. While this is true of the overwash plains of some regions, it is hardly true of these formations as a whole in New Jersey. While it is true that such plains would in general be less productive than many other areas if the climate were dry, the moist climate of the Atlantic coast generally affords sufficient rainfall to relieve, where it does not neutralize, the ill-effects of a very porous soil. In many places the fertile fields to be seen on these plains are a sufficient contradiction of the idea of their sterility. A considerable part of Morristown is built on such a plain, which is continuous with the plain stretching northward to Morris Plains and beyond. The condition of both native and cultivated vegetation in this region indicates its general fertility.

The plain on which both Plainfield and Scotch Plains stand, and which stretches thence to the moraine on the east, is another illustration of an overwash plain, differing in some respects from that at Morristown. From the broad plain east and south of Plainfield, there is an extension southwestward to Bound Brook and Somerville, but its typical character is not preserved far beyond Bound Brook. The Raritan river, between Bound Brook and Somerville, cuts through the plain, which has a considerable development on the south side of the river in the vicinity of Hillsboro and South Bound Brook. Further east the approximate southern limit of the overwash

plain is marked by a line running from South Bound Brook through New Market, New Brooklyn and Metuchen, though the gravel extends south of this line near the latter place. More or less material of the same origin skirts the moraine to the southeast as far as Ford's Corners. Within this area the depth of stratified drift varies greatly. At Scotch Plains it is often as much as thirty-five feet in depth, and in some places the rock lies twice that distance from the surface, although it is not certain that the seventy feet of material overlying the rock is all glacial gravel. Toward the borders of the plain the drift is very thin. The overwash is coarser near the moraine and finer at greater distances from it. Exposures showing the material of which the plain is composed may be seen at various points about Plainfield, Dunellen and Evona.

It is interesting to note that within this plain, about one mile due west of Fanwood and an equal distance southwest of South Plains, a low hill of "yellow gravel" rises ten to twenty feet above the glacial gravel. The same gravel appears again at the base of the Highlands west of Plainfield, just above the margin of the overwash plain.

South and southeast of Denville overwash gravel and sand border the moraine, occupying the space between it and the railway. A half mile and more northwest of Denville there is a pitted plain standing in the same relation to the moraine. This is perhaps as good an example of a pitted plain as has been found adjacent to the moraine. The Succasunna Plains region is another illustration of overwash, though this region has not yet been specifically studied. Doubtless other areas of overwash gravel will be found along the moraine at points further west.

Areas related to overwash plains within the moraine.—Within the moraine there are some areas of gravel and sand representing the material carried on beyond the ice after its edge had receded beyond its position of maximum advance. Sand and gravel plains within the moraine are somewhat extensive. They do not belong to the class of overwash plains in the sense that they lie outside a terminal moraine, but their genesis places them in the same general category. For the most part the sand and gravel areas here referred to occupy valleys or other low areas. Large areas in the valley of the Hackensack, especially about Westwood, Norwood, Rivervale and Demarest, belong to this category. Also a considerable area northeast of Paterson, in the valley of Saddle river. These areas are not all plane;

many of them, indeed, are very far from plane. Narrow belts of a similar character occur along the valleys of the Ramapo and Wanaque rivers. These have closer relationship with valley trains than with overwash plains. A considerable area of gravel stretches southward from Millburn to Cranford, in the valley of the Rahway river. This plain is interrupted at Springfield by kames. The sand is here very deep. A well at Springfield is reported to have penetrated ninety feet of sand before the rock was reached. Bordering the secondary moraine (kame belt) between Waverly and Locust Grove, there is a gravel plain extending southeast from Salem to Elizabeth. This is locally pitted.

Another gravel-and-sand plain of considerable extent is found between Pompton and Lincoln Park. The plain is two miles or more in width and five or six in length. Its principal development is on the west side of Pompton river. It declines to the south less than ten feet to the mile. Its surface is very level, as the designation Pompton Plains suggests. The depth of gravel is undetermined, since the deeper wells of the region, scarcely more than twenty feet deep, do not reach its bottom. The gravel is coarse to the north, and is coarser below than near the surface. It is covered, especially southward, with a thin coating of loam. In places it is ill-drained or artificially drained, and here its surface is covered with a black soil, sometimes obscuring the real nature of the plain. The date of construction of this plain was doubtless after recession had carried the ice north of Pompton.

Subaqueous overwash plains.—About the edge of the ice there were sometimes bordering lakes. Lakes would arise in such situations wherever the topographic relations of the ice edge were such that the waters issuing from its melting edge found no escape. (See page 43.) The waters discharging from the ice into such a lake sustained the same relations to the ice as the waters producing the normal overwash plain. But the waters discharging into a lake, instead of spreading out on a land surface, effected a result somewhat different. The deposition takes place in a lake in the one case, not on the land, as in the other. While the constitution of the deposits will be similar in the two cases, their form will differ in one important respect. The overwash plain has a gentle slope more or less regularly declining from the moraine, against which its higher edge abuts. The overwash material has its greatest thickness next the moraine, becomes thinner

and thinner at increasing distances from it, and finally disappears, often without sharply-marked boundary.

In the lacustrine overwash plain, on the other hand, the phenomena are somewhat different. On reaching the lake, the glacial waters have their velocity suddenly checked, and therefore drop most of their load near the border of the lake, filling its shallow marginal part. But since most of the material is promptly dropped as the waters reach the lake, the surface of the plain resulting from long-continued deposition does not decline gradually and regularly without a sharply-defined topographic limit, but drops off promptly and more or less abruptly at the limit of abundant deposition, after the fashion of delta formations. The deposition in the lake where any given stream entered would indeed constitute a delta, which would gradually advance into the lake. If water were discharged into the lake at an equal rate all along the common margin of ice and water, and if all parts of the inflowing waters were equally laden with debris, and if the lake were of equal depth all along its margin, the margin of the lake would be filled with equal rapidity at all points—that is, a delta would be built lakeward from the margin of the water, all along the border of the lake, on the side where the drainage entered. But all these conditions would probably never co-exist, so that the filling would proceed unequally, but everywhere the plain of deposition would possess the steep outer face characteristic of delta deposits. From the moraine to its steep outer slope, the surface of the subaqueous overwash plain would decline gently, possessing the slope and the general features of an overwash plain, formed on a land surface. Indeed, the part of the plain nearest the shore would presently be built above the water-level, when it would receive additions after the fashion of a normal overwash plain. The following figures show the general relationship of the two types of overwash plains:

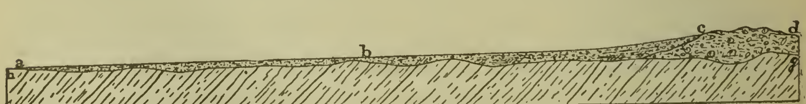

Fig. 2.

Diagram illustrating the relation of a subaërial overwash plain to the moraine and to the surface outside the moraine—c d, moraine; h g, the rock surface beneath the drift; a b c, the surface of the overwash plain, which abuts against the moraine, running far up on its slope, but not reaching its summit. The outward slope of the overwash plain is much greater nearer the moraine than further from it. The material of the overwash plain is coarsest nearest the moraine, and becomes finer and finer with increasing distance from it.

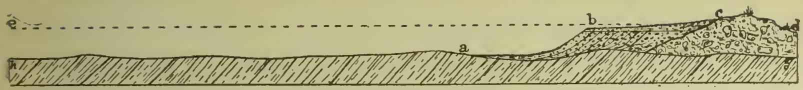

Fig. 3.

Diagram illustrating the relation of a subaqueous overwash plain to the moraine and to the extra-morainic surface; *e b* is the level of the lake in which the gravel and sand were deposited. The other letters have the same significance as in Fig. 2. The chief points of difference are the steeper slope below *b*, and the structure of the stratified deposit.

After the ice and lake were gone, gravel plains thus formed could be distinguished from those formed on the land by the fact that their outer slopes descend abruptly from the outer edge of the surface of the delta plain. The plains here described might with equal propriety be called *delta plains* or *subaqueous overwash plains*. To distinguish them from other forms of delta plains, and to express at the same time their relationship to subaërial overwash plains, the designation *subaqueous overwash plains* is here proposed. Beyond the abrupt slope, marking the outer edge of abundant deposition, there should be found fine silt and clay, the characteristic deposits of more quiet waters.

Gravel plains of the type here described have been found at several points both without and within the moraine. The overwash plain skirting the moraine from Morris Plains southwest to Summit bears evidence in its abrupt outer face that its margin was formed beneath water. The abrupt outer face here referred to may be well seen a mile or so southwest of Morris Plains, in the south part of Morristown, a quarter to a half mile southwest of the Delaware, Lackawanna and Western railway between Morristown and a point a little south of Convent, and again west of Madison. Here the plain is frequently seen to descend abruptly from about the 360 foot contour line. The abrupt decline is often as much as seventy or eighty feet.

Within the moraine, striking plains of this type are to be seen north of Preakness and northwest of Franklin lake. Two miles north of Preakness there is a well-defined gravel plain at an elevation of 340 to 360 feet. To the north it becomes somewhat undulatory. The plain covers more than a square mile, and slopes gently to the south. At its southern terminus, one and a half miles north of Preakness, it falls off abruptly 90 to 100 feet. The depth of the sand and gravel is not known, but it is great. Excavations appear not to have reached its lower limit. Even on the lower plain south of the higher, the sand is deeper than the underground water-level, so

that wells do not make known its full thickness, but even here it is known to be more than twenty feet deep in places. A mile or so south of Preakness the sand becomes thinner, and beneath it laminated clay is said to exist.

A mile or so north of the abrupt south face of the Preakness plain, there is another plain of similar character at the still higher level of about 400 feet, likewise with an abrupt south face. This plain is much less well defined than the one south of it, and perhaps does not belong to the same category. At the other locality, two miles northwest of Franklin lake, and an equal distance south of Oakland station, there is a similar subaqueous overwash plain of smaller extent.

In the southeastern part of Boonton, south of the canal, and a mile northeast of Montville, north of the railway, occur further illustrations of the subaqueous overwash or delta-plain type, formed where glacial waters discharged into marginal lakes. The plain north of Montville is well seen along the upper road leading from Montville to Whitehall. The railway makes deep cuts through its edge, revealing great thicknesses of stratified drift.

VALLEY TRAINS.

Down many of the valleys leading southward from the moraine, trains of gravel extend for great distances. A conspicuous example of a valley train is found in the valley of the Delaware as far south as Trenton and beyond. Others are found in the valleys of the Musconetcong and the Black rivers. Similar trains of much less extent are found in many small valleys which served as avenues of glacier drainage. These valley trains are especially developed in the extra-morainic parts of valleys which have their sources within the moraine. To a lesser extent, and in relations which made them less distinct, gravel trains occur within the moraine.

The method of deposition of these gravels corresponds, in a general way, with the method by which all alluvial plains are developed. A stream deposits when it has more load than it can carry. The water issuing from the edge of the ice was loaded with gravel, sand and earthy material. Of these materials, as the deposits prove, the streams had more than they were able to carry to the sea. The coarse materials were therefore dropped along their channels. By this process, the channels of those streams which were avenues of discharge

for the melting ice, were gradually filled. The capacity of the channels was thereby lessened. At the same time the supply of water was abundant, and the streams must have flooded their valley bottoms beyond the confines of their channels. In any given valley the waters outside the channel would have built up the flood plain at the same time that the channel was being raised by deposits within it.

So long as deposition on the flood plain kept pace with the deposition in the channel, both would rise, but their relations to each other would not be altered. The valley bottom would be built up steadily; or, if we may coin a word to designate a process for which a name is needed, the valley bottom would be *aggraded*. As the flood plain and channel were aggraded, the flood plain would be widened, since a valley is in general wider at any given level than at any lower one. A deep filling, or, what is the same, extensive *aggradation*, would result in a wider flood plain, higher than the old valley bottom. Under these circumstances the filling would not be homogeneous. The coarser material would be found along the main channel, where the current was swiftest, while the material deposited on the flood plain on either side of the channel, where the waters were more sluggish, would be finer. The result would be such as is indicated in the following figure:

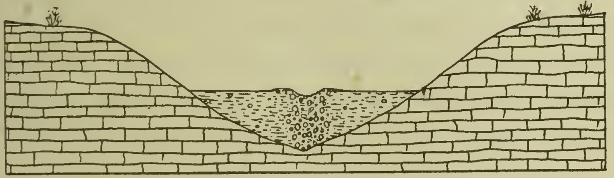

Fig. 4.

Diagrammatic cross-section of an aggraded valley, where the whole width of the flood plain was built up at an equal rate, the stream holding its course throughout the process of aggradation. The coarser material in the center marks the position of the channel, where the current was swifter, while the fine material on either hand represents the deposits on the flood plain.

Ordinarily, if not always, the aggradation would take place somewhat differently. In the case of an overloaded stream, the deposition in the channel will exceed that on the flood plain. The channel and the flood plain are then aggraded unequally, the former more rapidly than the latter. Natural levees would tend to develop on the borders of the channel, and these would help to confine the stream to its channel.

The condition of things thus brought about is unstable, as the history of any river through its flood plain abundantly shows. In the case of a stream fed by a melting glacier, the excess of water which would flow through the valley whenever warmer temperature caused a rapid melting of the ice would frequently cause the stream to break through its levees. Once the stream's course was fixed on the flood plain lower than the former channel, it would be difficult for it to return. Thus the old channel is abandoned, and a new one established on what was before the flood plain, on the one side or the other of the earlier channel. The old channel now becomes a part of the flood plain. (See Fig. 5.) The new channel and its bordering flood plain will suffer aggradation, as did the old, until the new channel reaches an elevation above that of some other portion of the flood plain, when the stream will again be likely to shift its course in time of high water, the main current establishing itself along the lowest course open to it.

This new course will in time be aggraded just as its predecessors have been. With each shift of the channel, the old channel and its bordering plain constitute the new flood plain of the stream. The line of most rapid deposition shifts with the shifting current. The alluvial material would be coarser along the line of the current, and finer on the flood plain adjacent. Any point in the valley might be receiving now coarse, now fine debris, the one over the other. A cross-section of such a valley train might show, by the nature of its materials, various positions which the main current occupied during the process of aggradation. This is diagrammatically represented in Fig. 5.

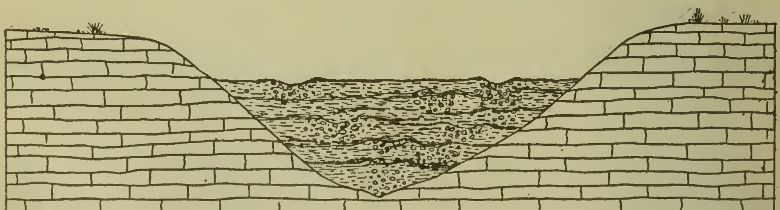

Fig. 5.

Diagrammatic cross-section of an aggraded valley in which the stream shifted its course many times in the process of aggradation, as depositing streams are known to do. The coarser materials in the various positions, from below upward, represent the successive sites of the channel, two channels being represented in the last stage. In nature, the shiftings of the channel are much more frequent than here represented, so that the coarse materials marking the temporary sites of the channels do not remain so distinctly separated from each other.

Because of its own work in aggrading its channel, therefore, a depositing stream is forced to meander in its own valley. Although with each change of position the current seeks the lowest path accessible to it, the lowest path accessible at any stage is higher than that accessible at any earlier stage. Thus the stream's flood plain gradually rises by the aggradation of the valley bottom all along the line where deposition is taking place.

It is probable that the actual process of aggradation in the case of valley trains was somewhat less simple. A stream which is aggrading its valley is likely to branch, as do delta-building streams. The distributaries given off follow, severally, the history sketched. Instead of one stream meandering in its valley, therefore, there was probably often a network of streams, joining each other and parting company at irregular and inconstant intervals. In this case the structure of the aggraded plain would be slightly different from that in the cases previously described, since many streams, rather than one, were concerned in its construction. The coarser materials would be deposited along the lines of the swifter currents. Since they frequently shifted their positions, the distribution of coarse material would also vary. The structure of the valley train would be more complex the more the stream branched. This complexity of structure is that which characterizes the valley trains of glacial gravel and sand. A further element of complexity arises from the fact that even an aggrading stream may be temporarily and locally a cutting one, ever and anon removing some of the deposits already made, but ultimately replacing them by others.

During the ice epoch the conditions for the aggradation of valleys leading from the moraine were exceptionally favorable. Large volumes of water, heavily laden with glacial debris, coursed through them. The valleys were filled to considerable depths. In many cases their rock bottoms, which mark the downward limit of preglacial erosion, lie many feet below the surface of the present gravel plains.

At the close of the aggradation, it is probable that the sand-and-gravel valley trains were essentially flat, but furrowed with a more or less complicated network of shallow channels occupied by streams which may have united so as to cover the whole of the plain in time of flood. During each flood it is probable that the courses of these minor streams were altered.

THE DELAWARE VALLEY TRAIN. TRENTON GRAVEL.

Although the age of the Delaware valley gravel train has given rise to much discussion at one time and another, there can be no doubt that the gravel of which it is composed was deposited as sketched above during that stage of glaciation when the ice edge stood near Belvidere. The process of deposition at and below Trenton may have been somewhat different, as will be noted later. It is proposed to discuss in detail the questions involved in the origin, distribution, and relations of various parts of the Delaware valley gravel at an early day, together with a historical sketch of opinion concerning it. Many of the data for such discussion are already collected. A few pages only will here be given to the subject.

Development of terraces from flood plains.—The Delaware gravels are believed to have once formed a continuous plain or train of valley drift, stretching from the moraine just below Belvidere down to and beyond Trenton, on the New Jersey side of the river. But this plain is no longer continuous. When the ice retreated from the position of its terminal moraine, the glacial waters left their burden of debris higher up the valley. When the ice had receded so far to the north that the river was no longer burdened with debris from the glacier as it flowed through the flood plain made while the ice stood at Belvidere, it set to work to carry away the material which had been temporarily laid by in the flood plain during the time it was overloaded. In this task it was perhaps aided by a gradual elevation of the upper portion of the drainage basin of the Delaware as the ice receded, an event which would accelerate the velocity of the stream, and therefore increase its erosive power. This suggestion is not made on the basis of facts observed in New Jsrsey, but because the movement here referred to is known to have taken place in corresponding latitudes subsequent to the close of the glacial period. In the work of removing the filling deposited by the glacial stream the river has since been engaged. Where the preglacial valley was narrow, and where the gravel plain was therefore narrow, all or nearly all the gravel has been removed, as at Phillipsburg, a short distance south of Phillipsburg, one and a half miles south of Carpentersville and three-fourths of a mile south of Kingwood station. It frequently happens that traces of the gravel remain scattered over the valley slopes, even where there is no recognizable part of the old plain. In this case the

index of the height of the old plain is the limit of scattering pebbles of glacial age on the slopes of the valley.

Where the valley was wider, the gravel and sand have frequently been mainly or wholly removed from the one side, leaving some remnant of the gravel plain on the other. Thus at Hutchinsons, just north of Riegelsville, one mile south of Holland station, and at several points between Tumble and Trenton, the terrace has been removed from the left bank of the river, while it still remains on the Pennsylvania side.

Remnants of the terrace still remain with equal frequency on the New Jersey side of the river where they are wanting on the opposite side. This is true at Hutchinsons, Carpentersville, Milford, Tumble and Byram, as well as at other points. In other situations gravel still remains on both sides of the valley, as at Trenton.

In the progress of degradation which succeeded that of aggradation, the river lowered its channel to such an extent that its waters no longer covered the glacial flood plain, even when the stream was flooded. The glacial flood plain then became a terrace. Where the stream's course chanced to be on one margin of its flood plain at the time it was changed from a depositing to a cutting stream, the old flood plain remained as a terrace on the opposite side of the valley only. If, when the stream began to cut into its glacial flood plain, its course chanced to be in the center of the valley, or remote from either margin of the glacial flood plain, remnants of the same would remain on both sides of the new channel, as bordering terraces.

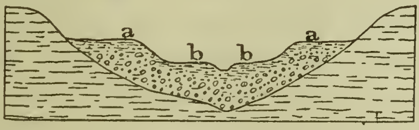

Fig. 6.

Diagram showing cross-section of an aggraded valley after some of the filling has been removed. The original level of the valley train, *a a*, is now a terrace, below which the stream has developed a new flood plain, *b b*. The stream is confined to the channel between *b* and *b* except in time of flood.

Secondary terraces.—In process of time, the lowered channel developed secondary flood plains at various levels below that of the glacial flood plain. Still later, as the river sank its channel so low that at any given point its waters no longer covered the new flood

plain in time of flood, this flood plain became a terrace. Thus in postglacial time arose secondary terraces below the level of the original glacial terraces.

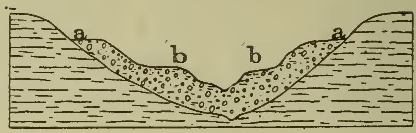

Fig. 7.

Diagram illustrating the development of secondary terraces. Through erosion, the stream in the center of the valley (Fig. 6) has sunk its channel so low that the old flood plain (*b b*, Fig. 6) has now become a terrace (*b b*, Fig. 7), while the stream runs at a lower level and is developing a new flood plain on either side of its channel.

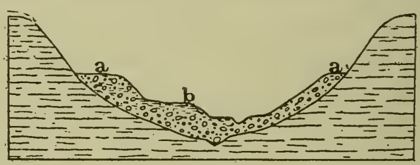

Fig. 8.

Corresponds with Fig. 7, except that the channel is not cut in the middle of the valley. Because of its eccentric position, a secondary terrace has been developed on one side only.

Since these later secondary terraces were made during the time when the river was less flooded, and therefore less swift than when it was discharging water from the edge of a melting ice-sheet, the material of the lower flood plains, or the material of their surface parts, at any rate, is finer than that of the higher terrace. This would be likely to be true of all the material deposited by the river on the lower flood plains while these were developing, but not of the deeper parts which were deposited in glacial days, and which have not been removed. In some situations, two or three secondary terraces occur below the original terrace of glacial age. These simply represent successive flood plains. Thus at Martin's creek, above Phillipsburg, there are three terraces,* or remnants of them, twenty-three, thirty-three and eighty-five to ninety feet, respectively, above the river. The highest represents the glacial terrace. The thirty-three foot terrace represents a flood plain of the river where it had sunk its bed

* Survey made by Asher Atkinson.

fifty-odd feet into the glacial flood plain, while the twenty-three foot terrace represents a still later stage in the history of postglacial degradation. It will be observed that between the time when the river flowed at the level of the highest (glacial) terrace, and the time when it had developed a flood plain at the thirty-three foot terrace level, it had lowered its channel nearly twice as much as it has in all subsequent time. It would not be safe to conclude, however, that the time between the formation of the ninety foot terrace and the thirty-three foot terrace was to the time since the formation of the latter, as two to one (57 : 33). But it would be safe to conclude that the thirty-three foot terrace is considerably younger than the glacial terrace. The twenty-three foot terrace is, of course, still younger. Considerable stretches of terrace at about this level occur along the river, and correspond with what is often known in other regions as "second bottoms." In extreme floods, within the memory of living men, the water has covered many of the terraces corresponding to this level. It is therefore very young, relative to the glacial terrace.

Among other points, secondary terraces may be seen three-fourths of a mile south of Martin's creek, one mile north of the bridge at Phillipsburg, below Holland station, at Frenchtown, Stockton and Titusville. They are often much wider than the upper glacial terrace, which is at many points altogether wanting, or represented only by traces of gravel on the hillside considerably above the lower, secondary, postglacial terrace, as already indicated. The superficial parts of the secondary lower terraces are almost uniformly of finer material than the uppermost. Since only the superficial parts are commonly exposed, the lower terraces sometimes appear to be somewhat sharply contrasted with the upper in constitution.

It has frequently been remarked that the levels of the terraces do not match each other in such wise that they can be regarded as parts of a connected whole. But if we interpret rightly, the apparent discrepancy lies in the fact that the attempt has been to put the primary and the secondary terraces together. It is manifest that they cannot agree in height. The remnants of the original terrace should be found to be consistent with each other, in the matter of elevation, and we believe they are. In the secondary terraces, on the other hand, a regular system can hardly be expected, since they may have been formed in different parts of the valley at different times, and therefore when the river was at different levels.

One interesting feature of the surface of the terraces should be mentioned. At several points where a boss of rock rises above the gravel plain, a low ridge of gravel stretches off down the valley from it. Similar ridges are sometimes found below a projecting point in the bluff. Some of these little ridges run to a point down the valley, while others spread out like a fan. Such a ridge of gravel occurs two and a half miles south of Martin's creek, below Harmony station. The ridge has a length of about a mile, and like all such ridges, is higher near its upper end. Again just north of Phillipsburg, where the valley widens suddenly, a similar ridge stretches southward from the projecting point of gneiss. This spur is on a lower, not on the highest, terrace. This spur is twenty-two feet high at its upper end, and tapers to a point down the valley. It has a length of about thirty rods. This is higher than most of the spurs or ridges, and has a steeper slope.

A mile or so above Carpentersville another gravel spur upon the glacial terrace leads off from the projecting point of the rock bluff, where the latter recedes from the river. Another spur of gravel occurs a mile or so above Lambertville, stretching southward again from a projecting rock spur. It is traceable for more than half a mile, being highest and most narrow at the north, and widening and flattening to the south. Similar spurs of gravel are known on the Pennsylvania side of the river as well. These gravel ridges and their relationships were made out independently by Messrs. Knapp and Whitson.

In general, the terrace is composed of much coarser material near the moraine than further south. It grades from very coarse gravel (stones six to twelve inches in diameter abundant) near the moraine to fine gravel further south. Bowlders, however, are liable to occur at any point. They are far from rare at Trenton, as may be seen at the gravel pits. These bowlders were doubtless carried to their present position by icebergs floating down the flooded river.

Height and slope of the Delaware valley gravel train.—The altitude of the original valley train of last glacial age can now be determined at various points by the remnants which still remain in the form of terraces. The altitude of the south end of this valley plain at Trenton is now about sixty feet. The altitude of the plain near the northern terminus, between one and two miles below the moraine south of Belvidere, is about 300 feet. The plain just below the

moraine is therefore about 240 feet higher than its southern part at Trenton. The distance between these two points is about sixty miles. A regular decline from a point two miles below the moraine, to Trenton, would therefore give an average fall of about four feet to the mile, measured on the surface of the terrace, if it were continuous. The decline is, however, much more rapid near the moraine than further down the valley. Measurements by Mr. Atkinson give 300 feet for the altitude of the terrace at Roxburg station, about two miles below the moraine, and 230 feet for the corresponding terrace at Phillipsburg, ten miles further down the valley. This indicates an average decline of seven feet per mile for the first ten miles, the first two miles of the plain being omitted in the calculation. Between Phillipsburg and Holland station, a distance of about twelve and a half miles by the course of the valley, the surface of the terrace declines from 230 feet to abcut 175 feet, or an average of about four and a half feet per mile. Between Holland station and a point fourteen miles below, near Byram, the surface of the terrace has declined from 175 feet to 120 feet, or rather more than three feet per mile. From the last point to Trenton, a distance of about twenty-two miles, its decline is about sixty feet, or about two and three-fourths feet per mile.

If the terrace remnants of the old plain be measured in terms of their elevation above the river adjacent, instead of in terms of elevation above the sea, instructive results appear. Between Roxburg and the upper part of Phillipsburg the river has a fall of fifty feet, while the gravel plain declines seventy feet in the same distance. From this it follows that the terrace at Roxburg (ninety-five feet) is about twenty feet higher than that at Phillipsburg (seventy-five feet), as compared with the river. In other words, the terrace has declined two feet per mile faster than the river. Between Phillipsburg and Holland station the river falls thirty-five feet, while the terrace declines fifty-five feet. The terrace at the former place (seventy-five feet) is therefore about twenty feet higher than that at Holland station (fifty-five feet), as compared with the river. The terrace here declines about one and three-fifths feet per mile faster than the river. Between Holland station and Byram the river has a fall of about fifty feet, while the terrace declines about fifty-five feet, leaving the terrace only five feet higher at the former point (fifty-five feet) than at the latter (fifty feet), as compared with the river. Through this part of its course

the river therefore declines less than one-half foot per mile faster than the terrace. Between Byram and Trenton the river falls about sixty feet, while the terrace declines about the same amount. Hence at these two points the river and the terrace sustain essentially the same relation to each other in point of altitude. Between Belvidere and Trenton, the river therefore has a less fall, by about forty-five feet, than it had in that part of the last glacial epoch when the valley train of gravel was completed, if there has been no differential change of level in western New Jersey since that time.

Southward limit of the Trenton gravel.—On the New Jersey side of the river, the Trenton gravel, as this terrace material has been called, is not distinctly traceable below the southward bend of Crosswicks creek, about three miles below Trenton. Below this point, traces of the same sort of gravel are seen at various points, but they are for the most part traces only. At many points occasional pebbles of what appears to be Trenton gravel (glacial origin) are found mingled with a much larger quantity of gravel derived from the older "yellow-gravel" formation, but which is believed to have been worked over, mingled with the glacial gravel, and deposited anew in the valley in or since glacial times.

Among the localities south of Trenton where traces of the Trenton gravel have been recognized, chiefly by Mr. Knapp, the following may be mentioned: Three-fourths of a mile west of Kinkora, on the west bank of the creek, at an elevation of about thirty feet; in the west part of Florence at about the same level; a mile southwest of Florence, and at other points in the vicinity a little further south; along the bank of the river from the mouth of the creek tributary to the Delaware below Florence, to East Burlington, but not known to extend back from the bank north of East Burlington; in the south part of Burlington at an elevation of about ten feet; at various points between Burlington and Riverton and Palmyra, at levels corresponding with the last. At some of these points, the evidence that what appears to be Trenton gravel really is such, is not altogether satisfactory. It is evident, both from its composition and disposition, that that part of the gravel which lies south of Bordentown is somewhat different in character from that above, and that it has had a somewhat different history. It is not yet clear how far this gravel is fluviatile and how far estuarine (ice perhaps aiding in its transportation), how far it is glacial in age, and how far postglacial.

On the Pennsylvania side of the river, the Trenton gravel is found further south, although its limits are by no means clearly defined. Mr. Whitson has given some attention to the distribution of the formation on this side of the river, and the following points are given largely on the basis of his determinations. It is exposed at various points along the line of the Pennsylvania road for a distance of five miles below Morrisville, opposite Trenton. It extends back from the river a little below Fallsington for a distance of fully four miles. Two and three-fourths miles southwest of Fallsington it is said to be sixteen feet deep, and to rest on a sharply-defined surface of stiff clay. The gravel is here composed in part of yellow gravel mixed with much that is of glacial age. Beyond Mill creek the limits of the gravel become ill-defined. On Turkey hill, three or four miles southwest of Trenton, the Trenton gravel appears to extend up the slopes to an altitude of about fifty feet, although the main body of the hill is of other material. In the vicinity of Bristol the Trenton gravel may be seen on the river bank at various points. It is also exposed in the upper part of a pit one and a half to two miles south by west of Bristol, a short distance south of the railway. Its height here is about thirty feet. The lower part of the pit shows gravel of greater age, mixed with that of later date. A half mile from the river, at Dunk's ferry, at an elevation of less than twenty feet, gravel similar to that further up the valley may be seen. Below this point there are some traces of it, to Tacony at least. But such elements of sand and gravel as have the aspect of aqueo-glacial formations are so far exceeded by material of other sorts that their identification as Trenton gravel, on the basis of constitution, is a matter of uncertainty. From the standpoint of topography, it is reasonably certain that the low plain bordering the river much further down stream is the time equivalent of the Trenton gravel terrace. The islands in the river appear to be made up largely of Trenton gravel material. This material is, however, largely sand instead of gravel. Burlington island has more gravel than the other islands. How far these low-lying Trenton gravels may be in secondary position, and therefore postglacial, has not been determined.

Human relics in the Trenton gravels.—It is no part of the present purpose to discuss the question of human relics in relation to these gravels, further than to say that no human relics of any sort have been found by any member of the present survey in the terrace of

glacial age. This testimony is purely negative, and furthermore has little significance even as negative testimony, since no especial search has been made for the objects in question, although our eyes have been open for them, whenever fresh exposures have been seen. In one of the secondary terraces, between Raubsville and Riegelsville, Pennsylvania, however, not much above the present flood plain of the river, artificially-chipped stones were seen by the writer, in company with Messrs. H. C. Mercer, W. H. Holmes and Charles Laubbach, in trenches which Mr. Mercer had caused to be opened for the purpose. But the terrace in which these chipped stones were seen cannot be very old. Its surface parts, at least, where the chipped stones were seen, are in origin very much nearer the present time than the close of the last glacial epoch, as the relation of the terrace to the glacial terrace above, and to the river below, shows.

This relation of chipped stones makes pertinent the suggestion that in all future investigations of the question of the relation of human relics to the Delaware gravels, the relic-bearing gravels and sands themselves should be carefully studied, with a view to determining whether they are really of glacial age, or whether they are parts of a secondary terrace of much less antiquity. It is hardly necessary to remark that even if human relics occur in postglacial terraces, this does not at all touch the question of paleolithic man, concerning which there is so much difference of opinion. It touches only the question of glacial man, and this only indirectly, for the existence of human relics in postglacial terraces does not at all disprove their existence in terraces of glacial age. It may be added further, that if no human relics whatsoever be found in undisturbed glacial gravels, their absence constitutes only negative evidence against the existence of glacial man, and negative evidence in such a case could probably never be demonstrative. Reference is here made to the subject of human relics only for the purpose of calling attention to the necessity of determining accurately the age of the formations in which they occur, before any trustworthy generalizations can be made touching their bearing on the question of man's antiquity. Attention is also called to the ease with which relics in secondary terraces might be referred to glacial terraces, and to the general fact that human relics may be found in stratified and undisturbed gravel or sand which is not of glacial age, in a valley which contains gravel and sand known to be glacial, and that in this case the relics do not afford the slightest evidence of man's existence in glacial or preglacial times.

SECTION VIII.

TRENTON GRAVELS OUTSIDE THE DELAWARE VALLEY.

In this connection brief mention will be made of some further occurrences of the Trenton gravel outside the Delaware valley, in relations which may throw some light on various questions connected with the glacial drainage of New Jersey.

Aside from the unexpectedly abrupt cessation of the well-defined Trenton gravels a little below the city whose name they bear, there are other anomalous features in their distribution. A good deal of attention has been given to this point, and many data accumulated which will be made use of in a later and fuller discussion of the Trenton gravels. But enough will here be said to indicate the nature of the problems which this distribution involves.

Instead of being restricted to the immediate valley of the Delaware, the Trenton gravels spread over a considerable area to the east and northeast of Trenton, though in the immediate vicinity of the city they do not rise much above sixty feet. They cover most of the surface which lies below that level.

In the Assanpink valley.—The Assanpink creek, coming in from the northeast, joins the Delaware at Trenton. Its course lies through a low belt, which, as far as Baker's Basin, nowhere rises to the sixty foot contour. Indeed, the belt which is less than sixty feet above the sea, has a considerable width adjacent to the creek. Just below Baker's Basin the course of the Assanpink (followed up stream) turns to the east, while from the northeast, in line of projection of the lower course of the Assanpink, the Shipetaukin creek joins it. The junction of the Shipetaukin with the Assanpink is less than four miles from Stony brook, at Port Mercer, and nowhere along this line between Port Mercer and Trenton does the surface rise above sixty feet. Where Stony brook and Shipetaukin creek approach each other most closely, they are only about one and a half miles apart.

Four miles below its abrupt change from a southerly to a northerly course, Stony brook joins the Millstone near Princeton, and the Millstone finds its outlet through the Raritan into Raritan bay. Between

Trenton and Raritan bay, therefore, there is a passage by way of Assanpink and Shipetaukin creeks, Stony brook, the Millstone and Raritan rivers, *no part of which rises above the level of the glacial gravels at Trenton.*

The low belt from Trenton to the Raritan is a tolerably direct one, its course being northeast by north from the Delaware. It will be readily seen from the map accompanying this report and showing the drainage lines of the State, that the bend in the course of Stony brook at Port Mercer is a remarkable one. It is below this bend that the brook forms a part of the passageway just located. The land between the bend of Stony brook and Shipetaukin creek is low and marshy. Until prevented by artificial means, this intervening marsh is said to have drained in both directions in time of high water. At this point, therefore, the present water-shed between the Delaware and the Raritan, except in so far as interfered with by human agencies, is no more than a marsh less than sixty feet above the sea and yielding water to both systems.

Up the Assanpink, above the junction of the Shipetaukin with it, the land bordering the stream does not rise to an elevation of sixty feet, until a point a mile or more above Lawrence station is reached. In harmony with the correspondence in level of the Trenton gravel at Trenton and this low area to the northeast, the Trenton (glacial) gravel is found extending up the Assanpink valley above the junction of the Shipetaukin. It is well exposed near Baker's Basin, at an altitude of sixty feet. Following up the Shipetaukin, it appears at more than one point, and in the vicinity of Port Mercer, near the sharp bend of Stony brook, Trenton gravel occurs in the form of a distinct bench or terrace, rising somewhat above the sixty foot contour line, but not reaching the seventy foot contour. At Port Mercer there is known to be at least fourteen feet of gravel, all of which is reported to be like that at the surface, which, in character, corresponds with the gravel at Trenton.

In the valleys of Stony brook and the Millstone river.—Following down Stony brook below its bend, the same gravels are found almost continuously, in quantity sufficient to be traceable, to a point southeast of Princeton, where they occur fully up to the seventy foot contour line. Beyond this point traces of the same gravel occur to the point where Stony brook joins the Millstone. To the southeast, above this junction, the Millstone valley is below sixty feet in elevation. The

Trenton type of gravel is found to run up this valley from the point of junction with the Stony brook, to the point where the brook from Bear swamp comes in. Above this point it has not been found, and probably does not exist. Up the Millstone valley, from the point where Stony brook joins it, the gravel does not reach above the sixty foot contour, and not always up to it.

Down the Millstone, from the point where it is joined by Stony brook, there are the merest traces of Trenton gravel until Kingston is reached. Just below this point, Trenton gravel occurs up to the sixty foot contour line, at least (Knapp). North of Kingston, meager traces of the gravel have been found at various points. One mile above Griggstown, it is found at an altitude of seventy feet (Knapp). From this point to East Millstone, traces of the gravel are found at levels not varying greatly from those already noted. Between East Millstone and Weston the gravel is continued, here largely mingled with local (red shale) material. At the railroad crossing near Hillsboro, three miles southwest of Bound Brook, there is a deep exposure in gravel of similar character, the red shale of the vicinity contributing generously to its make-up. In this vicinity the gravel plain has a considerable development. To the west the same type of gravel continues up the Raritan to Somerville. It is also continuous to the north-east with the glacial sand-and-gravel plain at Bound Brook, except for the interruption caused by the Raritan. The plain at Bound Brook is continuous with the overwash plain at Plainfield. Near Bound Brook its maximum elevation is about sixty feet.

Along the Millstone, best seen in the vicinity of East Millstone, there is sand and sandy loam extending considerably above the traces of Trenton gravel. It has the general aspect of the sand associated with the newer drift. In one place it has been observed to reach the height of ninety feet above tide, though it rarely rises above seventy or seventy-five feet. Above fifty or sixty feet, pebbles have not been seen to be associated with the sand. Its limits are ill-defined, and it certainly rises much higher at some points than at others closely associated, where conditions for its existence seem equally favorable. It is altogether possible that its irregular distribution is the result of wind-work, operating upon an aqueous sand which was originally limited to a level below that which the sand now reaches.

In the Raritan valley below the Millstone.—Down the Raritan from Bound Brook, traces of gravel of the same character are found at

several points before New Brunswick is reached. It is nowhere obtrusive, and nowhere forms a distinct terrace. But unmistakable traces of it occur at various points on the south side of the river, between Bloomington and New Brunswick, and more rarely on the north side of the river, up to elevations of about sixty feet. On both sides of the river, the indubitable occurrences of the gravel are several miles above New Brunswick. Just below New Brunswick, on the north side of the river, traces of the same gravel are distinctly recognizable for a mile or more below Highland Park, at an elevation of about forty-five feet.

From this distribution, if we are right in our determinations, it will be seen that the Trenton gravel has a traceable presence between Trenton and Raritan bay, unless there be a slight interruption just above New Brunswick.

Hypotheses to account for the distribution of the Trenton gravel.— To account for this distribution of Trenton gravel several hypotheses have been framed and considered, but no positive conclusion has yet been reached. Further study, we are confident, and especially critical determinations at a number of significant localities, will enable us to arrive at the true explanation. But meanwhile it may not be unprofitable to point out some of the possibilities of the case.

1. So soon as the existence of the gravel along the course of the Millstone was known, it was at once thought that in preglacial and glacial time the Raritan river might have had a course up the Millstone to the mouth of Stony brook, thence up the Stony brook valley to its bend, and thence down the valleys of the Shipetaukin and Assanpink creeks to the Delaware river at Trenton, and that this stream brought from its upper courses the Trenton (glacial) gravel. There are many features of the region, particularly some details concerning the courses of rivers, which would be consistent with this hypothesis. But when the valley of the Raritan above Somerville is examined in detail, it is found that the gravel occurring along the Millstone has no counterpart in the valley of either branch of the Raritan. While the valleys of both branches of the Raritan have more or less gravel, it belongs to another category, and is not to be mistaken for gravel equivalent to that at Trenton. Neither branch of the Raritan seems to have been the avenue of any notable glacial drainage, in the last glacial epoch. The hypothesis that the Mill-

stone-Stony brook-Shipetaukin-Assanpink gravel came down the upper branches of the Raritan, was therefore set aside.

2. On the supposition still that until and during the last glacial epoch the Raritan ran up the Millstone valley from the point of their present juncture to the mouth of the Stony brook, thence up Stony brook to Port Mercer, thence over to Shipetaukin creek, and down this creek through the Assanpink into the Delaware, it was thought that the gravel might have entered the valley from the Plainfield region, through Bound and Green brooks, tributaries to the Raritan from the northeast. On this supposition, as on the other, the present Raritan valley, from Bloomfield down, was not the course of the Raritan river earlier than late glacial times.

There seem to be three more or less serious difficulties in the way of accepting this hypothesis. The first is that the Plainfield plain of glacial gravel becomes chiefly sand before Bound Brook is reached, while the material further down the supposed valley (up the Millstone) is sometimes coarser than that further north. The material should become finer with increasing distance from the ice edge. This difficulty is perhaps not so great as it seems, since something of the seeming coarseness in the glacial gravel of the Millstone valley is due to gravel of local origin, and not to glacial gravel which might have come down from the Plainfield region. Over the Plainfield plain, too, the overwash may have been finer, while down the main line of discharge, where the current was strong, coarser material may have been carried.

The second difficulty is that the level of the gravel far down the supposed valley (up the Millstone), as at Kingston, is rather higher than that at Bound Brook, while that at Trenton, fully thirty miles from the Raritan by the course of the valley, is equally high. This is not necessarily fatal to the hypothesis, since postglacial warping of the surface might have changed the original continuous decline from Bound Brook to Trenton, in such wise that the gravel at the latter place is now as high as that at the former, while at intermediate positions, as near Princeton or Kingston, it might be higher or lower than either.

The third difficulty is that at least a trace of gravel which quite certainly seems to be connected with the last glacial drainage, occurs at similar elevations at some points down the present course of the Rari-

tan below Bound Brook, to a point beyond New Brunswick. If the Raritan formerly went down to Trenton, and if the stream was first diverted to its present course below Bound Brook in late glacial or postglacial time, it might be conceived that the traces of gravel along the river from Bound Brook to New Brunswick and beyond, were deposited by the stream in postglacial time. But there are serious difficulties in the way of this suggestion. If this were the history, it would seem probable that a small stream flowed through what is now the lower valley of the Raritan, before the Raritan was diverted to it. By head erosion this minor stream might have worked back until it tapped the Raritan above Bound Brook, at the point where it turned up the present course of the Millstone. In this case, the valley of this minor stream at New Brunswick must have been a very considerable valley, before its head tapped the Raritan at Bound Brook. If, then, the Raritan were diverted, its waters might have flowed at a level of sixty feet immediately below the point of diversion, but they would hardly have been expected to flow at an altitude of forty-five feet a mile or more below New Brunswick. From the presence of last glacial gravel in the Raritan valley below New Brunswick at an elevation of forty-five feet, we are led to believe, therefore, that the Raritan's course from Bound Brook to Raritan bay may not be the result of postglacial piracy at the hands of a stream flowing into Raritan bay.

The outlet by New Brunswick to Raritan bay might have been brought about in another way. If the glacial waters aggraded the old course of the Raritan to such an extent as to raise the flood plain in the vicinity of Bound Brook to the level of the divide separating the valley from the sea to the east, the waters might have flowed over this divide, as well as down the old valley (up the Millstone). In this event the eastward-flowing waters, having a much shorter course to the sea and an equal amount of fall, must have had a much higher gradient, and must therefore have had a higher velocity. They would then possess greater cutting power. The softer nature of the rock along this course would have facilitated the work of deepening the new channel. This line of outflow would have gradually secured the advantage of the other, and finally would have carried all the water in this direction. If this were the history, the third difficulty mentioned above would be avoided. The others would remain, but neither seems to be insurmountable.

3. If the central part of the State were depressed sixty or seventy feet, tide-water could pass from Raritan bay to Trenton. Glacial waters discharging into the strait thus formed would bear in gravel and sand, which might be distributed as we now find it. If this were true, we should have a rational explanation of the cessation of the Trenton gravel as a distinct river terrace at some distance above the mouth of the Delaware. While deposits of equal age must have been formed in the estuary further south, they would be somewhat unlike those of the valley above. They would be, on the whole, of finer materials and of more heterogeneous composition, since mingled with the Delaware river (glacial) detritus, there would be such material as the waves along the estuary had access to, and such material as minor, non-glacial streams, might bring in. If this were the explanation we should, it would seem, find the shore lines of the old estuary. These have not been found, nor is there anything in the topography which seems to give decisive evidence of such a submergence as the hypothesis here suggested necessitates. In the constitution and structure of the plain of equal age with that at Trenton, but further down the stream, there are some features which lend color to the hypothesis here under consideration. But nothing of an altogether decisive nature has been found. The presentation of all the data now in hand bearing on this point will be reserved for another discussion.

If this be the correct interpretation of the phenomena, we find an explanation of the occurrence of Trenton gravel up the Assanpink for a short distance above the junction of the Shipetaukin, and up the Millstone a little beyond its junction with Stony brook. In both cases the distribution of the gravel would indicate that the tidal current through the strait, if such there were, came from the northeast, and advanced to the southwest. At two points at least between the Raritan and Baker's Basin, there are low ridges or spurs of the Trenton gravel running longitudinally in the valley, which seem to point to movements of water in this direction. They are analogous in form and in relationship to the spurs or ridges of gravel already referred to in the valley of the Delaware above Trenton. One of these ridges stretches southward from a boss of gneiss one and a half miles south of Baker's Basin. It has a length of half a mile and a fall in this distance of ten feet. Small a ridge as this may be, it is noticeable in its flat surroundings, and its likeness to the ridges in the

Delaware valley further north is significant. A similar ridge has been noticed south of Kingston, partially buried by sand (Knapp).

If, during the last glacial epoch, or its closing stages, tidal water found a passage-way between Raritan bay and Trenton by the course indicated, the Raritan valley for a short distance above Bound Brook would have been converted into a shallow estuary. Since no glacially-flooded stream bearing glacial debris entered the estuary, its deposit should be of the slack-water type. Since the surrounding rock is red shale, the deposit to be expected would be a fine clayey earth, composed largely of red-shale materials, but with some traces of such other materials as the river was competent to bring to its estuary, and with traces of such loose and coarse materials as may have lain upon the surface immediately about the border of the estuary. It should be noted that the great filling of sand and gravel at Bound Brook, South Bound Brook and Hillsboro, if produced by glacial drainage, as indicated on page 119, would have ponded the Raritan above, and would have produced like effects in its valley, in the form of slack-water deposits.

At about the point where the sand and gravel of the Plainfield-Bound Brook-Hillsboro area disappears to the west, there is such an earth as that described above, in the valley of the Raritan. It is distinctly laminated in many places, and is limited to about the same level as the sand and gravel at Bound Brook and vicinity. This subaqueous surface earth extends up the valley from Findern to Raritan and beyond. West of Somerville its surface is a little higher than further east. Traces of it occur up to the eighty foot contour in the vicinity of Raritan. It has a similar disposition when traced up the valley of Peters brook. It may be seen (1) in the brick-yards at Somerville, as at Ross' pit; (2) at various exposures along the streets up to altitudes of rather more than sixty feet, and (3) in the banks of some of the creeks, especially one in the northeastern part of Somerville. It was also seen (1892) in temporary exposures on the main street of Somerville.

Some of the sections of this clay deposit are as follows, commencing with the uppermost layer:

Section in bank of creek, east part of Somerville.

(3) Five feet of laminated hard red clay containing occasional foreign pebbles, mostly of yellow-gravel type. The clay glazes when cut with a trowel.

(2) Six to eight feet of a very hard, compact layer made up of fine particles of red shale, water-worn and rounded, with a generous sprinkling of yellow-gravel pebbles, the whole imbedded in a firm clay matrix. A large percentage of the red-shale bits are sharp and angular, resulting from the breaking up of the water-worn fragments. The layer contains enough clay to cause it to glaze when cut. Likely to be mistaken for red-shale residuary when the exposure is not well shown.

(1) Three to four feet (bottom not shown) of firm, clayey sand, cutting smoothly.

Section at Ross' clay-pit, one-third of a mile north of the preceding section.

(3) One to two feet of white or yellow clay (leached).

(2) Six inches to one foot of stratified red-shale bits and yellow gravel. This layer can be traced more or less continuously around the pit, but it changes thickness abruptly.

(1) Nine to ten feet of hard red clay, with a sprinkling of yellow-gravel pebbles, and *very small*, rounded red-shale bits. Glazes when cut. Somewhat laminated, but not distinctly so.

This slack-water deposit is nowhere known to attain a thickness of more than twenty feet, and it is generally much thinner. Its thickness varies greatly within narrow limits. Its existence seems to be perfectly consistent either with the hypothesis of a tidal strait or with the hypothesis that the Raritan valley was temporarily dammed by sand and gravel discharged into it from the north, near Bound Brook. Microscopic examination of the clay about Somerville, with a view to determining whether it contains fresh-water or marine diatoms, may throw light on its origin. No fossils have been seen in the clay.

There is some independent evidence that the land about Raritan bay was somewhat lower than now in relatively recent time. It has not yet been possible to fix the exact time of this depression, in terms of glacial chronology, but there is little reason to believe that it was

so late as the last glacial epoch. The evidence of the lower land is found in certain locally well-defined terraces, which appear to be shore terraces, on the south side of Raritan bay, and at a few points on the north side. On neither side do the terraces affect the glacial drift. The youthful aspect of the terraces, and the finding of a single, small, glacial bowlder on the terrace south of the Raritan, opposite Martin's dock, three miles east of New Brunswick, and of an occasional last glacial pebble on the surface of the terrace near South River, would seem to possibly connect the terrace, and therefore the depression which gave rise to it, with the last glacial epoch. But the evidence for this connection is confessedly slender, since the last glacial pebbles referred to have been found only on the surface, where their position may be the result of human transportation. The absence of terraces in the glacial drift at Perth Amboy, and along the moraine on Staten Island, seem to indicate clearly that the sea has not stood notably higher than now at these points since the ice withdrew. In this statement, I do not leave out of mind the plain at New Dorp, S. I., which I think is to be otherwise explained than by a post-glacial submergence.

On the whole, the evidence does not seem to be altogether decisive between a tidal current, and a change in the course of the Raritan in glacial time, as an explanation of the distribution of the Trenton gravel. We incline to the latter. Either explanation would seem to account for many collateral facts, particularly concerning the courses and conditions of the streams tributary to the Raritan drainage system. Further study will be given to this problem during the coming summer, and its solution, it is hoped, reached.*

The preglacial course of the Raritan.—Even if the depression to the extent of letting the sea through the valley between Trenton and Raritan bay be the true explanation of the distribution of the Trenton gravel, it does not follow that the Raritan did not, up to that time, find its debouchure at Trenton. If not up to that time, it may have done so at some former time. There is much reason to believe that this was the fact. But into the discussion of the evidence bearing on

*After the preceding discussion was written, the Annual Report of New Jersey for 1880, heretofore inaccessible to me, came to hand. In it, I find (pp. 79, 85 and 88) that Prof. Cook advocated the idea that tidal waters advanced up the Raritan to the mouth of the Millstone, and up the Delaware to Trenton, and that a "narrow sound" existed between Bound Brook and Trenton "in the Millstone depression."

this point we will not enter further than to remark that the valley of the Raritan below Bound Brook appears to be a young valley, as shown both by the trench-like character of the valley itself and by the insignificance (in size) and, therefore, youth of its tributaries, and that some explanation of the course of the low valley belt between Bound Brook and Trenton must be had. The preglacial Raritan may have been its cause.

Valley trains along other streams.—In the case of the other streams down which valley trains extend, the streams have effected less erosion since the last glacial epoch and the terraces are not so high. In the valley of the Musconetcong at Hackettstown, and for a few miles below, there is a train of gravel. The gravel train heads at the point where the moraine crosses the valley, about a mile north of Hackettstown. It has here an elevation of about 600 feet, and forms a flat about a mile in width. Its decline is at first rapid, being about forty feet in the first quarter of a mile, but quickly becomes more gentle. Below the first quarter of a mile the gradient of the gravel train to Stephensburg, a distance of six miles, is about sixteen feet per mile. The river has a fall of 120 feet, or twenty feet per mile, in the same distance. The gravel, therefore, is found at greater elevations above the stream near Stephensburg than further up stream, if the highest part of the train extending a quarter of a mile from the moraine be left out of consideration. The gravel in the Musconetcong does not constitute well-marked terraces. This, however, is the accident of later erosion. There is abundant drift in the valley of the Black, but it appears to be of the nature of overwash, rather than valley train.

SECTION IX.

LAKE PASSAIC.

In the Annual Report of 1880, Prof. Cook made mention of the existence of a lake in glacial times, in the region southwest of Madison, including the area of the Great Swamp. He represented the outlines of this lake upon a map, and gave it the name of Passaic. Since that time traces of the lake have been looked for by various geologists, but with negative results on the part of some observers, and with meager positive results on the part of others. So far as we are aware no publication of late results or observations has been made, though Prof. W. M. Davis gave the writer localities where features suggestive of the former existence of the lake had been noted by him.

A priori considerations.—A study of the topographic maps makes it clear than when the ice of the last glacial epoch reached its position of maximum advance, there was a considerable area southwest of Morristown and Madison favorably situated for the formation of a temporary lake. The area thus situated includes the Great Swamp and the relatively low area surrounding it. Into this area must have flowed the waters from a considerable section of the edge of the ice which lay at Madison and vicinity.

The present drainage from the region is through the Passaic river. But in the moraine stage of the last glacial epoch, it would seem that the Passaic must have been blocked by the ice at Stanley, thus preventing the escape of water down this valley.

In other directions the barriers were even more certain and impassable. On the northwest and west the highlands rise with unbroken front to a height several hundred feet above the Great Swamp. On the southeast, south and southwest are the great trap ridges, through which there are no passes by which the water might have found escape from the basin, except at great heights, when the present course of the Passaic was closed by the ice. On all sides, therefore, there seem to have been barriers to the escape of the water. This condition of things, it would seem, must have given rise to a lake whose existence would have continued until the ice had receded so far

to the north as to open up an outlet to the east or northeast, along the present course of the Passaic.

The lowest part of the Great Swamp is now less than 230 feet above tide. Three miles west and a little north of Liberty Corner, at an elevation of 331 feet, occurs the lowest point in the rim of this supposed basin, providing always that the outlet by the present Passaic valley was closed. It is not easy to see how this outlet could have been open, and it is therefore not easy to see how the lake can have failed to exist. If the waters filled the basin to the level of the Liberty Corner outlet, the maximum depth of the lake must have been more than 100 feet. The water would have occupied the area between Second and Third mountains, as well as the area of the Great Swamp and its environs.

The beginning of the lake, if it existed at all, probably dated from a time earlier than that of the maximum advance of the ice. If the topographic and drainage relations of the present day correspond closely with those of preglacial time, and so far as concerns the area of the supposed lake basin this seems to have been true, the lake must have come into existence when the advancing ice reached the point where it blocked the drainage outlet of the Passaic basin. This would seem to have been when the ice reached the vicinity of Paterson. The river might have kept its course open beneath the ice for a time after the ice reached and crossed it, but it would hardly seem probable that it could have done so during the whole of the period of advance from Paterson to Madison. After the lake came into existence, the further advance of the ice would have encroached upon the northeastern portion of the lake, displacing the water and diminishing its area until it had destroyed all that part of it which lay northeast of the terminal moraine. When the ice occupied its most advanced position, therefore, the lake was at its areal mimimum, if its level remained constant. If there was at any time an outlet lower than the Liberty Corner noteh it does not now appear.

As the ice receded from the terminal moraine, it would seem that the lake must have increased its area by occupying that portion of the surface laid bare, so far as it was below the level of the lake. It does not appear that an outlet so low as that near Liberty Corner could have been found until the ice had receded as far as Paterson, unless the water drained out b3neath the ice. In this case the extra-morainic lake occupying the Great Swamp and its surroundings would have

expanded to the northeast so as to cover, within the moraine, the area from Boonton on the north, to Stanley on the south, and from Morristown on the west to Caldwell on the east. At this time the area of the lake would have been more than twice as great as at the time of maximum ice advance. Within the moraine it would have included the Troy Meadows, the Black Meadows, the Great Pine Meadows and the Hatfield Swamp, together with the surrounding low lands. The Great Swamp area of the lake would have been largely separated from the area to the northeast by the terminal moraine, whose crest, between Morristown and Chatham, would have projected above the water as a low ridge.

Such, according to the topography, would seem to be the necessary drainage conditions of the Passaic basin during the advance of the ice after it closed the Passaic outlet, during the time of its maximum extension, and during the early stages of its recession until the valley of the Passaic was again opened. That portion of the lake northeast of the moraine must have had a width of nine or ten miles and a length of twelve, while the portion southwest of the moraine must have had a length of eleven or twelve miles and a maximum width of half its length. Its total area at the time of its greatest development must have been something less than 200 square miles.

The marks Lake Passaic should have left.—When the positive evidences are sought confirmatory of the existence of the glacial lake which *a priori* considerations seem to warrant belief in, they are found to be less general and less distinct than might have been anticipated. It might have been expected that such a lake would leave distinct marks of various kinds. Among them the following:

1. *Shore features.*—So considerable a body of water was large enough to allow the generation of considerable waves, and if its existence were prolonged through any considerable interval of time, the waves and shore currents ought, it would seem, to have left indubitable records of themselves. Wave-cut terraces, beaches, spits and deltas are among the phenomena to be looked for along the border of the supposed lake.

2. *Iceberg deposits.*—Bergs of ice, carrying stony debris, must have sometimes moved out upon the lake. Their burden of drift should be found wherever the bergs grounded, or wherever melting caused it

to be dropped. If the lake existed, therefore, we should expect to find occasional bowlders and other drift deposits up to the levels which mark the border of the lake.

3. *Bottom deposits.*—Such deposits would be expected to be more abundant, the longer the life of the lake. Over the bottom of the lake we should expect to find more or less silt and clay, the only product of the glacial drainage, aside from that transported by icebergs, which would have been carried far beyond the border of the lake at any particular time.

There are perhaps other features which should give evidence of the former existence of the lake, if its existence were a fact. But the features mentioned are those most easily defined and recognized. If all of them are present in harmonious relationships, the conclusion is certain that Lake Passaic was a fact. If the shore features alone are present in unequivocal development, they are quite sufficient to establish the fact of the former existence of the lake. Neither of the other features would be in itself so decisive, since each may be simulated by the products of other agencies.

THE SHORE FEATURES.

Several factors influence the strength of development of shore features, but especially the strength of the waves, the materials upon which they work, and the duration of the lake. Other things being equal, the shore features would be most likely to find most distinct development where the lake's existence was most protracted. This would have been in that portion of the lake beyond the moraine. But this was the smaller part of the lake, where waves would have been, so far north, less effective. Such shore features as might have been developed in advance in that part of the lake basin that was subsequently filled with glacier ice, would probably have been effaced by the ice during its occupancy. If the lake to the northeast of the moraine were re-formed on the recession of the ice, shore features might have been developed. But the duration of this part of the lake at this stage may have been brief, so that the development of well-marked shore features was not favored. In any case, the duration of this part of the lake during the retreat of the ice must have

been much shorter than that of the other part which lay outside the moraine. So far forth, the shore features should be better developed outside the moraine.

At the time the ice edge stood where the moraine is now, the lake would have had a length of about twelve miles and a maximum width of six, if it filled the basin to the outlet near Liberty Corner. On the northeast its shore would have been the moraine; on the north, northwest and west the crystalline schist highland, and on the southwest, south, and southeast, the second trap ridge. Long hill or Third mountain would have been an island, or perhaps a long spur, joined only at its eastern extremity to the moraine crest. If the life history of the lake were short, the waves on so small a body of water would probably not have been sufficiently strong to effect great results in eroding the crystalline schists or the trap ridges. Wave-cut terraces of any considerable extent would hardly be expected. But terraces built by the waves and by shore currents are often of rapid construction, and might have a very considerable development even in a short-lived lake, wherever an abundant supply of detritus was accessible to the waves.

The greatest supply of detritus would manifestly have been on the northeast side of the lake, where the moraine formed its shore. Not only would the shore have been easily eroded here, but there would have been a constant supply of detritus discharged into the lake from the ice on this side. Against the moraine, therefore, we should expect a stronger development of shore features than along the highland or trap-ridge borders of the lake. The highland border would be a more favorable location for the development of shore features than the trap-ridge border, both because of a probable greater covering of loose material and because of the greater drainage into the lake from this side.

If the strong winds blowing over this supposed lake were more commonly from one direction than from others, the waves would be stronger on the side toward which the wind was blowing, other things being equal. On such side, therefore, the shore features should be best developed if other conditions were constant.

When the shore features are looked for, they seem to be found at some points. But they are often less distinct, and far less persistent than might have been expected, if Lake Passaic had so long an existence as the conditions seem to favor.

Shore features along the moraine.—Along the moraine border of the supposed lake, gravel and sand deposits, occupying the position of an overwash plain, have something of a terrace form. From the line of junction of this border plain with the moraine, the plain slopes gradually to the southwest after the fashion of an overwash plain, built on a land surface. At about the 360 foot contour line, the slope changes abruptly, becoming notably steeper. The upper, gently-sloping part of this terrace plain may have been constructed above the surface of the lake. This portion of the terrace plain may represent the original border of the lake which was first filled by inwash from the northeast. As the deposits continued, the line of most active subaqueous deposition was transferred lakeward by the filling of the shoreward margin of the lake. Presently the marginal part of the lake may have been filled to the level of the water, and even built above it. Thenceforth, deposition would take place upon this surface, now built above the lake. The result would be the construction of a subaërial overwash plain on the surface of the earlier lacustrine terrace, or subaqueous overwash plain. The subaërial part of the plain, like all normal overwash plains, would slope gradually in the direction of drainage. On the other hand, the abrupt edge of the plain could only have been developed beneath water, and, in existing relations, only beneath shallow water. The level of the water, as indicated by these terrace plains, must have been something like 360 feet, an elevation about thirty feet higher than the outlet which, according to the topographic maps, water in the same area would find to-day near Liberty Corner, if the Passaic outlet were closed. The abrupt descent on the lakeward side of the terrace plain is well seen half a mile or so southwest of the railway from Morristown to Convent. It it likewise distinct just west of Madison. The same features are repeated between Summit and West Summit, and in the southwestern part of Stanley.*

Shore features along the highland.—Along what must have been the highland border of the lake, if it existed, shore features are not distinct. There are now and then faint indications of features which suggest an old shore line, but nowhere do these indications become distinct and decisive.

Shore features along the trap ridges.—Along the face of the trap

* These flat-topped plains were noticed by Prof. Cook, and were interpreted as evidence of the former existence of the lake.

ridges, both on the northwest face of Long hill and of Second mountain, there are at several points shallow beds of distinctly stratified, water-worn, but not well-rounded gravel, composed almost exclusively of trap, which might be interpreted as marking the position of an old shore line, although they are not commonly in such quantities or so disposed as to give rise to shore features which are topographically distinct. So far as the waves of the lake were effective in producing gravel along the trap ridges, it would be composed principally of trap fragments, as these gravels are. If the lake were but temporary, the beds of gravel developed at any level would be shallow, and might not constitute marked topographic features. The absence of distinct beach features is therefore no proof that the lake did not exist.

Gravel beds of the sort here indicated have been found at a number of points, at levels which seem to correspond very closely with that of the terrace plains along the moraine from Madison to Morristown. Now and then, the gravel at or near the 360 foot level is sufficient to afford pits of considerable extent, and rarely distinct and characteristic topographic forms in the shape of narrow terraces. Similar gravel beds would be likely to develop at any level below the upper limit of the lake where the water stood for a sufficient length of time. The occurrence of similar beds of gravel below an altitude of 360 feet is therefore to be expected, unless the lake were suddenly drained, following its maximum development. The existence of similar gravels below the maximum height could therefore not be cited in evidence against the existence of the lake at the level of 360 feet.

Trap gravel bordering the trap ridges has been seen at the following points, at or near the 360 foot line: (1) On the road leading over the ridge south of east of Long Hill, and about one-third of a mile from that place; (2) about one-third of a mile due north of Sterling (not on road); (3) a half mile or so northeast of Millington, on the east-west ridge road, just east of the point where it is joined by a road from the south; (4) a quarter of a mile west-northwest of the last-named locality; (5) about a mile northwest of Millington and a half mile southwest of Lyons station along the roadway (pit); (6) rather less than a mile west-southwest from the last-mentioned locality on the north-south road which crosses the western extremity of the Long hill trap ridge (Schrader); (7) rather more than a mile southwest of Liberty Corner, just south of fork in highway; (8) three miles north

of Liberty Corner, where a well-defined spur (spit) of trap gravel projects from the southwest side of the 360 foot hill. All these localities are on Third mountain or on the Long hill range.

Closely associated geographically are similar occurrences of gravel (9) less than a half mile northwest of Lyons (Schrader), here running up to 380 feet at least according to the topographic map, and down to the railway at 320 feet; (10) along the railway a half mile south of Basking Ridge station (Schrader), the gravel here being mainly of shale; (11) a half mile east of Bernardsville, at the cross-roads and vicinity, where the gravel is reported to be thirty feet thick; (12) a half mile northeast of the last-named place, where the gravel is mainly gneissic. There are traces of the gravel at various other points in this vicinity, less readily located because not on roads or near points which are easily defined. In all these cases the level of the gravel is about 360 feet, now running a little above this line, according to the maps, and often falling a little below it. In some of the localities last mentioned the gravel is not exclusively of trap material, but the differences are only such as the geological formations of the immediate vicinity, including older and higher drift, might lead one to expect. At a number of points the gravel is so disposed as to constitute a more or less distinctly marked bench or shore terrace. This is true at the locality just east of Bernardsville (the 9th above), to a less extent of that a half mile to the northeast (the 10th above), and of that south of Basking Ridge (the 8th above).

On Second mountain there is (13) a bed of similar trap gravel at a point rather less than one and a half miles southwest of Union village, on the east side of the north-south road leading from Sterling to Washingtonville. At this point there is something of a bench developed, apparently composed of gravel. In it a shallow pit has been opened.

Similar occurrences of gravel doubtless exist at other points, but except along roadways, or where pits have been opened, they are not easy of detection.

Red shale gravel on Long hill.—The trap ridges are sometimes flanked with shale up to the 360 foot contour. Wherever the waves of the lake beat against shale instead of trap, the less resistant character of the shale would have allowed it to yield more readily than the trap. Here more pronounced shore features might be expected. Reference has already been made to the shale gravel at two points in the

vicinity of Basking Ridge. At two other points at least the red-shale gravel is known. At a point less than a mile west of New Providence, where the road ascends the Long hill ridge, there is a spit-like ridge of red shale gravel running out from the red shale which flanks the trap ridge. Near the road a considerable pit has been opened. The lower end of the spit-like ridge is only about 240 feet high, but it runs up to an elevation of more than 300 feet to the northeast. The absence, or relative absence, of other sorts of gravel, seems to make the reference of the spit to wave-work altogether rational. The other spur of gravel, located by Mr. Whitson, is similar in character, and is situated about three-quarters of a mile northwest by west from Berkeley heights. In it there are no considerable exposures.

It would thus seem that there are phenomena at various points along the shores of the supposed Lake Passaic which seem to justify the hypothesis of its existence. The fact that the shore features occur at and near an altitude of 360 feet instead of 331 feet, the line of a present outlet to the southwest, presents an apparent, rather than a real, difficulty. To this reference will shortly be made.

But at still higher levels there are features very similar to those just mentioned which do not seem referable to Lake Passaic, and if these similar phenomena at higher levels must be otherwise explained, why assume the existence of the lake to explain the lower?

Gravels above the 360 foot level.—About two miles south of the center of Morristown there is an extensive pit in coarse, stratified trap gravel, at an altitude of about 370 feet according to the topographic map. The trap fragments are distinctly worn, but not well rounded. This is slightly higher than the border of the supposed lake, if we assume its level to be that indicated by the terraces between Morristown and Madison. It might be assumed that the higher gravel represents a higher level of the lake. Thus far it is not clear that the lake's surface may not have stood at 370 feet, if it stood at 360 feet. We shall presently see, however, that there is a limit, not far from 360 feet, above which the surface of the lake may not have risen. Less than a mile west of the locality last named are other extensive gravel pits, though no longer of trap. They are at an elevation of about 350 feet, but gravel similar to that in which the pits are located runs up nearly or quite to 400 feet on the same hill. It is not known to attain any considerable thickness above the level of the pits, and may not be stratified above an elevation of 360 feet. The surface gravel above

that level may be residuary, and may have been the source of supply of the thick beds below. The underlying rock is not exposed. The hill is continuous with that on which the trap gravel last noted occurs.

A mile or so northwest of New Vernon (Morris county) a hill rising to the height of 485 feet is coated, and thickly coated, with gravel, largely of sandstone and quartzitic nature, but containing fragments, and rarely large bowlders, of granitic or gneissic material. The underlying rock is not exposed, but it may be of quartzitic material, similar to the larger part of the gravel. Here again, for lack of exposures, it is not known whether the gravel of the higher levels is stratified or not. The gneissic and granitic material may be restricted to the surface.

Basking ridge, near the village of the same name, is another elevation composed of gravel and sand, or at any rate very heavily coated with them. Its maximum elevation is 485 feet. The variety of materials represented in the gravel at this locality is so great that it cannot be regarded as local, and therefore not a product of the lake shore, even if its altitude and its general disposition were consistent with such an origin. The gravels of Basking ridge are unlike those already mentioned and unlike those just east of Bernardsville, but a mile or so north of Basking Ridge station, which were referred to in connection with the possible shore features of the lake.

Again, about two miles west of Liberty Corner there are sands and gravels, as well as other sorts of drift, which are not referable to the supposed lake, both on account of their nature and their position. The drift here runs up to an elevation of more than 400 feet, in immediate proximity to the 331 foot outlet. It is evident that the high-level drift at this point cannot owe its existence to Lake Passaic, and it is probable that it is associated in origin with that at Basking Ridge, possibly with that at New Vernon and at various other localities where stratified drift is known outside the moraine and above the level of the lake, both within and without the supposed lake area.

It is clear, then, that in the mere presence of water-worn gravel along what may have been the shores of the old lake, we have no positive proof of the existence of the old lake. Gravel, and drift that is not gravel, occur at levels which are clearly much higher than that which Lake Passaic could have attained, and which as clearly antedate, by a very long period, any lake which may have occupied the basin in question during the last glacial epoch. With this last point

in view, we seem to have the explanation of the admixture of occasional pebbles of distant origin with the strictly local material in the shore gravels of Lake Passaic, if the gravels at the 360 foot elevation are to be referred to it. These foreign pebbles in the new gravel may well have been derived from an older generation of drift, of one sort or another, which occupied the ground before the days of the last glacial epoch. The meagerness of its contribution to the later shore gravels, if the 360 foot gravels be such, suggests that it was not abundant at the time of the last glacial epoch.

At no point above the 360 foot contour have topographic features, resembling those of shores, been seen. The existence of drift and gravel much above the level of the more probable shore features is, therefore, no evidence against the existence of the lake.

Did Lake Passaic exist in the first glacial epoch?—In this connection, a second question of interest is raised. If during the last glacial epoch the ice brought a lake into existence in the basin of the Passaic, why should it not have done so during an earlier glacial epoch, if, as we believe, such an epoch existed? May not some of these higher gravels be deposits made by the earlier Lake Passaic, before an outlet so low as that accessible to the last lake existed? We conceive this to be possible, and it is hoped that further study will bring to light the data necessary for a determination of the question.

ICEBERG DEPOSITS.

Berg deposits would be difficult of recognition in that part of the lake bottom which was covered by ice, but should be easy of detection in that part of the lake which lay beyond the moraine. To this part of the lake, bergs would not find ready access after the ice receded from the moraine, since from that time the moraine constituted a barrier to the bergs, which thenceforth must have been confined between it and the edge of the receding ice. The duration of the interval when bergs might have made extra-morainic deposits must have been restricted principally to the time of ice advance after the lake came into existence, and to the time of maximum ice extension, when the ice stood along the line of the moraine.

At various points throughout the area of the supposed lake, bowlders similar to those of the moraine are frequently found up to altitudes of 340 feet, and rarely at greater heights, up to 360 feet.

They occur occasionally in clumps, but more commonly they are isolated. They are more common below the upper limit of their range than at that limit. Some of them are of large size. No bowlders higher than 350 or 360 feet have been seen, which, on the basis of physical character, seem clearly referable to icebergs emanating from the ice of the last glacial epoch.

In some localities not distant from the moraine, there are considerable quantities of drift which may perhaps have been deposited by icebergs. At New Providence and vicinity this may be seen. It is of course possible that the ice at some stage pushed out a few miles beyond the moraine, and that this drift near New Providence and beyond, may be the result of such advance. If so, it was subsequently covered by water, for, if I interpret rightly, it bears the marks of subaqueous deposition, or of submergence subsequent to its deposition. Apart from this, the occasional fresh bowlders scattered over the supposed lake basin, and showing the marks of ice, seem to strengthen the conclusion, based on evidence afforded by shore phenomena, that Lake Passaic had a real existence.

It should be kept in mind that bowlders of granite, gneiss, quartzite and conglomerate are sometimes found above the probable shore line on the trap ridges. In such situations the gneissic and granitic bowlders are generally so far decomposed as to indicate their greater age, compared with the bowlders of corresponding material below the shore line. Above 350 or 360 feet, no granitic or gneissic bowlder of fresh appearance, or showing any sign of glaciation, has been seen, except possibly on the trap ridges close to the moraine. The existence of rather fresh (new drift) bowlders on the ridges here, is very probably the result of extension of the ice beyond the moraine at some stage of the moraine epoch, as already noted.

LACUSTRINE CLAYS AND SILTS.

The clays and silts which must have accumulated in the glacial lake, if it existed, should possess certain characteristics by which they may be recognized. They should be finely laminated, as are similar deposits of more recent origin. They should be of such materials as could be furnished by the waters draining into the lake in glacial times. The finer silts and clayey deposits should be found especially at some distance from the shore line, where the water was relatively

deep and where waves did not greatly disturb the bottom. They should be especially abundant, it would seem, toward that end of the lake which received the glacial drainage.

Clays and silts which seem to correspond very closely with those which might be expected in such a lake as Passaic must have been are found at various points. At the brickyards just south of Morristown, at an elevation of 320 feet and less, such clay may be seen. It is finely laminated, is slightly calcareous and contains unique concretions of calcium (lime) carbonate. In the vicinity of Pleasant Plains, seven miles or so south of Morristown, the low plain (about 230 feet) is covered to a considerable depth with similar laminated clay, equally rich in concretions, which are locally known as "clay stones," "clay dogs," "stone dogs," &c. The same clay extends over a considerable area in this vicinity, extending northeastward to Green Village and beyond, and westward and northwestward as far as Logansville, at least.

About Green Village the laminated clay is more or less covered with sand, which likewise mantles it for a mile or two further southwest. Near the western extremity of the area where the clay has been observed, it is likewise somewhat concealed by sand.

From the basin of the Great Swamp, the lacustrine or subaqueous clay reaches up on the lower portions of the north slope of Long hill to a height of at least 250 feet, though it is not always traceable to this height. On the bases of the mountain slopes, however, it has not characteristics identical with those of the clay on the lower land. It is here frequently concealed by sand, so that its exact limits are not easily determined. It is probable that the whole of the Great Swamp is underlaid by clay of lacustrine origin, although a part of the swamp clay may be of later date than the ice epoch itself, since this area may have remained in a lacustrine condition long after the main part of the waters had been drained away.

Between Second and Third mountains the existence of clay formed beneath water is also well known. It has not, where it has been seen, the distinctly laminated character which marks much of the lacustrine clay, but it possesses other features which seem to clearly indicate its subaqueous origin. In the summer of 1892 this was well seen in the vicinity of Berkeley Heights, in two temporary exposures then open. Near this place, the distinctly subaqueous clay does not seem

to run much above the 230 foot contour, and west of Millington it seems to be limited, according to the determination of Mr. Whitson, essentially to the 220 foot contour. This is hardly above the present flood plain of the river at this point. These clays may also be in part, at least, postglacial.

The depth of the subaqueous clay can rarely be determined, except where it is very shallow. Where it is deep, wells of any depth are rare, since water can be obtained near the surface. Not far from Long Hill village a well thirty feet deep is said to be excavated entirely in clay. A well has penetrated the clay to a similar depth northwest of Pleasant Plains. A half mile east of Pleasant Plains, according to Mr. O. Lindsley, a well seventy-two feet deep penetrated only soft "alluvial" material. The surface at this point has an altitude of about 230 feet. According to information from the same gentleman, a well one mile southwest of Green Village, at about the same elevation, reached red shale at a depth of twenty-two feet; while a third well, 172 feet deep, at the edge of the swamp a mile and a half south of Green Village, penetrated nothing that was recognized as rock. The lowermost third of this well was in sand, while the material above was of a clayey nature. Traces of subaqueous clay similar to that about Pleasant Plains may be seen beneath the sand at the edge of the sand-and-gravel plain bordering the moraine.

As already indicated, the topography of the clayey plain is level to the westward. The same is true of the corresponding formation between Second mountain and Long hill. The plane surface which prevails further west begins to be marked to the eastward by sinks and knolls, about half way between Sterling and Gillette, and the nature of the surface material is somewhat changed at the same time.

The presence of lacustrine clays and silts at certain points outside the moraine in the old lake basin seems to corroborate the evidence drawn from shore-line features and berg deposits that Lake Passaic had a real existence. On the other hand, the lacustrine clays are not so widespread, and do not in general reach such great heights as would have been expected. Their absence on the steep slopes may possibly be the result of subsequent removal. Yet the presence and distribution of some of the deposits belonging to this category do not seem readily explicable if the lake did not exist, however far short their development may fall of what might have been expected. At the

same time it is believed that some of the low-lying subaqueous clays may be of postglacial origin, after the lake had mainly disappeared, or at least after it had ceased to be a *glacial* lake.

EVIDENCES OF LAKE PASSAIC WITHIN THE MORAINE.

Within the moraine any deposits made by icebergs would be less readily recognized than without, since the whole of the intra-morainal area is covered with drift of the last glacial epoch. Except in especially favorable situations, it would be difficult, if not impossible, to recognize them.

Within the moraine the shore features might be expected to be well developed, except for the fact that the life of this part of the lake was shorter. If the lake had an existence during the advance of the ice, beginning with the blocking of the Passaic outlet, such shore features as might have been at first developed within the area subsequently covered by the ice would probably have been obliterated, or at any rate obscured, as the ice advanced and displaced the water occupying the territory within the moraine. The intra-morainal shore features which might be expected to exist at the present day, therefore, would be only those produced during the interval occupied in the recession of the ice from the moraine to the vicinity of Paterson, or until the water opened for itself an outlet beneath the ice.

Shore features within the moraine.—At various points within this region are features which, taken singly, seem altogether consistent with the idea that a lake occupied the region in glacial time. Along the inner face of the moraine, in the vicinity of Morristown, there are deposits of sand and gravel at altitudes of 360 feet and less, which have the aspect of shore-formed beds. A mile and a half northeast of Morristown, just north of the northern road to Malapardis and a quarter of a mile southwest of the 493 foot hill, there are pits in such gravel. On the road just south of the above, about a mile due west of Monroe, there is a spur of gravel which in some respects simulates a spit, though it is by no means a typical one. At some points between Convent and Monroe, on the inner face of the moraine, there are likewise gravel benches which suggest for themselves a shore origin. Near the edge of the ice, benches of gravel might be formed independently of shores, between the irregular margin of the ice and the moraine, in temporarily-inclosed basins. In this case

they would have been formed from the ice toward the shore, and should slope in this direction. The contrary is the universal fact so far as observed. Along the highway between Littleton and Parsippany distinctly-developed flats of loose gravel occur at an elevation of about 360 feet, which might be referred to the lake.

Similar topographic forms of similar constitution occur near Boonton, southeast of the canal. But here the gravel-flat is not at an elevation of 360 feet, but at 400 feet, more or less, according to the topographic map. Still further to the northeast, especially north and northeast of Montville, also at an elevation of about 400 feet, well-defined flats of gravel and sand occur. The best-defined is a half mile northeast of Montville and a mile and a half due west of Whitehall. The railway near Montville cuts through the projections of its edge. The flat here referred to is as perfect an example of a subaqueous sand plain, as could be desired. Throughout the Boonton-Montville-Whitehall area there are other benches at lower levels, less clearly defined.

The well-defined plain north of Preakness, at an elevation of 340 to 360 feet, seems clearly referable to a body of standing water. To this plain reference has already been made in another connection (see page 101).

There are also occasional indications of benches, perhaps referable to shores, along the trap ridge east of Livingston. They are rarely well developed. So far as traced, they occur at about 360 feet. At numerous points there are bench-like features considerably below 360 feet.

It will be noticed that the levels of these possible shore benches do not all correspond. That there should be lower ones below the highest does not seem strange. But that there should be isolated benches and plains so distinct as those at Boonton and Montville, so distinctly above the level at which the highest corresponding features elsewhere are well developed, was not to have been expected. From their situation they could hardly have been formed in basins isolated from the larger lake. It would hardly seem probable that the postglacial deformation of the surface could explain their position, since the change from one level to another does not appear to be gradual. Since the shore terraces at 400 feet, if such they are, are not continuous with those at 360 feet, the force of this objection is lessened,

though not destroyed, since terraces at the two levels are no more than four or five miles apart.

Lacustrine deposits within the moraine.—Lacustrine deposits of typical form have not been seen at many points within that part of the Passaic basin which lies within the moraine. Clay deposits, some of which are now used for brick and other purposes, are found within the lower parts of this area, but they are probably in part of postglacial origin. Such are the clays in the marshes just north of Whippany. Lacustrine clays occur beneath stony drift in the hill just east of the Whippany river, and fifty or sixty feet above the same, two miles southeast of Whippany (see page 57). In this connection the brick clays in the vicinity of Little Falls and Mountain View should be mentioned. They are at low altitudes (190 feet), but may be connected in some way with the lake's history. They are certainly of lacustrine type. The clays here are locally covered with till (Peet), which would suggest their origin at an early stage in the history of the lake. Microscopic study of these clays will perhaps throw some light on their origin and relations.

Much of the stony drift within the limits of the possible lake bears evidence of having been beneath water, if not formed in such a position. I am not able to say to what extent it was formed beneath the ice and subsequently submerged, and to what extent it was formed beneath water, by the conjoint action of water and icebergs.

The characteristics of stony unstratified drift, which seem to me to indicate a subaqueous origin, or submergence subsequent to subglacial origin, are perhaps more easily recognized than defined. A pronounced tendency to crack on drying is one of the most distinctive features susceptible of definite statement. Going along with this tendency, the subaqueous drift, as I have interpreted it, cuts in a manner recognizably different from normal till. The cut face has a smoother surface, comparable to that of "fat" clays. This is doubtless the result of the greater abundance of extremely-fine material, more completely filling the interstices between the coarser particles, where such are present. The fine particles of a clayey nature also often adhere tenaciously to the surface of the stones of the drift, coating them with a film which is not easily removed. These marks are those most easily seen at the surface. Others are revealed in deeper exposures.

Conclusion.—Altogether, the evidences of the existence of the glacial

Lake Passaic seem to be so numerous, and of such a nature, that it is not easy to see how they are otherwise to be accounted for. But there is the difficulty that they do not seem to be altogether harmonious. The shore marks below the common upper limit present no serious difficulty, since they may well represent lower levels of the lake during later stages of its history. There are suggestions of those features at numerous points at the level of 320 feet, which seem to mark a definite stage in the history of the lake. There is the much more serious difficulty that apparent shore features, according to the topographic maps, occur at heights altogether inconsistent with what seems to have been the highest level possible to Lake Passaic.

The Outlet of Lake Passaic.

It has been indicated that the lowest outlet which appears to have been accessible to such a lake is the notch west of Liberty Corner, at an elevation of 331 feet. It does not appear that this outlet can have been materially lowered since the lake disappeared. But the drainage of the lake through this outlet may have lowered it. If so, the outlet, when first established, was at some higher level. The notch is cut in hard, trap rock, and the water must have been relatively free from sediment, and therefore could not have possessed much cutting power. Nevertheless, it is possible that the narrow gorge, the bottom of which is at 331 feet, may have been cut during the existence of the lake, and by its outflow. If the narrow gorge were filled, the surface would be brought up to the level of about 360 feet. It would, therefore, not seem impossible to account for lake-shore features at 360 feet, supposing the drainage of the lake to have lowered the outlet twenty-nine feet.

The delta-like formations at an elevation of 400 feet, already referred to, cannot be accounted for by supposing the outlet to have been lowered from that level, for while the surrounding topography might warrant the belief that the outlet was lowered from 360 feet to 331 feet by the lake drainage, it would not warrant the assumption that it had been lowered from 400 feet.

The attractive influence of the ice-mass, and of the highland region north of the lake, may have exerted an appreciable effect on the surface of the lake water, and might account for some trivial rise of water above the outlet, in the northeastern part of the lake; but that influence could not have held the water up to 400 feet where apparent shore

features occur at that level, while it was low enough to develop shore features at 360 feet in localities no more than five miles distant. Every hypothesis which has suggested itself to explain the shore features at these discordant levels involves other difficulties as grave as those obviated by it.

The valley below the Liberty Corner notch should give evidence of having been the channel of great torrents of water, if Lake Passaic had its outlet in this direction. It has not been studied with sufficient care to warrant a statement as to the presence or absence of such evidence. But if present, it is not obtrusive. This point is one which will have received further attention at an early day.

SECTION X.

WIND-DRIFT AND RESIDUARY PRODUCTS.

Wind-drift.—Within the area which has been especially studied, there is relatively little dune sand. While in many sandy areas the surface sand has doubtless been shifted to a greater or less extent by the wind, dunes are not of common occurrence, even where the material for their development seems favorably disposed. According to Professor Culver, dune sand occurs at low levels on the east shore of Newark bay from Bergen Point to Marion, small dunes being developed southwest of West Bergen. There is also more or less dune sand on the east side of Bergen Point. Across the river from Ridgefield Park also, Professor Culver finds considerable areas which he believes to be more or less covered with dune sand. He has also found small mounds of blown sand opposite Hackensack on the east side of the river, and in East Paterson, near the glue-works.

The sand along the Millstone river near East Millstone has been referred to on a previous page. The higher parts of this may be of wind origin. There is also some sand at various points between Ambrose's brook, and Bound brook, south of New Market and Samptown, the origin of which is æolian. In none of these places does the sand constitute well-defined dunes.

In the area southeast of Great Piece meadows, the surface sand has doubtless been considerably shifted by the wind. The same is true of the low area along the Rockway north of the Troy meadows. It is difficult to differentiate the work of the wind from that of water in these areas, but the wind-work seems to be distinctly subordinate.

At various points along the coast from South Amboy southward, the wind has drifted considerable bodies of sand inland for short distances. This has sometimes taken the form of dunes, and sometimes has been scattered over the surface without developing into mounds and hillocks. The dunes are much more characteristically developed along the coast than elsewhere, and their recognition is easy. In the interior, dunes have an undetermined distribution. They are known to be developed in many places, as in the low sandy area east and southeast of Old Bridge.

Residuary earths.—A considerable part of the area lying between the glacial drift on the north and the continuous body of the yellow gravel on the south, is covered with the products of disintegration of the underlying rocks. It is hardly necessary to state that these residuary products vary with the formations which gave origin to them.

Triassic residuary products.—Where red shale is the underlying formation, the soil and subsoil are generally thin, and the outcrops of the shale are frequent. The residuary earth is so like the shale itself that no question concerning its origin could arise. On level surfaces where surface drainage is sluggish, and at the bases of slopes down which the surface earths have crept or been washed, the residuary products of the red shale are thickest. But even here the disintegrated material covering the shale is not usually thick enough to prevent frequent outcrops of the rock itself. The thinness of the red shale residuary earths is probably the result of two conditions; (1) the insoluble nature of the rock, making its disintegration a physical rather than a chemical process, and therefore limiting it mainly to the depth of roots, frosts, and considerable changes of temperature; and (2) the fineness of the residuary product, which makes its removal easy. It is the first of these conditions which makes the residuary soil so like the original rock in color and composition. Only where the residuary materials from the red shale have been shifted and redeposited by water (without admixture of foreign material), as is sometimes the case (see page 122), is anything else likely to be mistaken for red shale residuary, or the red shale residuary for anything else. It is certain that much of the red shale area, as now exposed, was at some time covered by later formations. These, whether yellow gravel and sand, or Cretaceous sands or clays, have in many places left traces of their existence, modifying to a greater or less extent the strictly residuary character of the red shale soil.

Where the underlying rock is sandstone instead of shale, the surface materials are recognizably different, being more sandy and less clayey in texture, and often lighter in color. The sandstone residuary generally resembles its parent rock less closely than does the shale residuary. This is because its chemical character undergoes greater alterations during the process of disintegration and weathering. The sand grains themselves are sometimes decomposable, and of such a character as to suffer various chemical changes which do not result in disintegration. The surface materials in the sandstone areas gully

less readily than those of the shale areas, probably because of their greater porosity, which allows the surface waters to sink, instead of compelling them to run off over the surface.

Where the underlying rock is conglomerate, as is sometimes the case in the Triassic area, the residuary product is an earthy gravel, the constituent pebbles of which were derived from the conglomerate. Where the conglomerate contained a great variety of materials they re-appear in the decomposition product. The gravelly earths in such situations might be readily mistaken for drift. Where some of the constituents of the conglomerate were decomposable or soluble, as granite, limestone, &c., disintegration gives rise to much earthy material, as well as gravel. In such cases, the residuary earths are often deep, sometimes completely concealing the underlying rock over considerable areas. The more considerable depth of residuary materials, as compared with shale areas, results from the fact that (1) disintegration is not restricted to the zone of frosts, but goes on actively to the depth of the permanent underground water level, and more slowly to still greater depths; and (2) the residuary products are in part coarse, and, therefore, often beyond the power of surface drainage to remove, and, on the whole, more porous, allowing rain water to sink beneath the surface, instead of forcing it to run off over the same, carrying away the residuary earths. The finer products of decay are distributed among the coarser, and by them their removal is prevented. The area of gravel southwest of New Vernon, referred to on page 65, may belong in part to this category, although the gravel on the lower parts of the hill has been seen to be distinctly stratified in one place, and is there certainly not simple residuary material. It may have been derived mainly from the upper parts of the hill, where the rock is not exposed. The fact that occasional bowlders of gneiss occur on the hill, as well as pieces of other kinds of rock which hardly seem referable to a possible underlying conglomerate, bears against the idea that the gravel covering is strictly residuary. Soo, too, the quartzitic gravel two miles southwest of Morristown, referred to on page 65, may be of residuary origin on the higher slopes of the hill. But at the level of the pits the gravel is distinctly stratified, and has been worked over and deposited by water, possibly by the water of Lake Passaic, even if its origin be local. In the absence of knowledge concerning the character of the rock beneath the gravel, the possibility of its residual origin must be recognized, although we have referred

to it under the head of extra-morainic drift. The same may be said of certain areas in the vicinity of Clinton.*

Trap residuary—Outside of the moraine, the trap ridges are generally covered by very stony earth, which possesses a character so distinctive that it is not to be mistaken for any other surface earth. Wherever a section from the surface soil to the solid rock beneath can be seen, the relation of this earth to the trap is evident, though in general appearance the clayey soil itself bears little resemblance to the trap. In this case the chemical changes incident to disintegration have been very considerable. A considerable portion of the rock has been carried away in solution, and the constituents which have remained have undergone extensive chemical change, particularly oxidation. The considerable content of iron allows the oxidation to effect very great changes in the color of the residuary earths, as compared with the original rock. It may be stated as a general rule that residuary soils most closely resemble their parent rocks when the chemical changes involved in their production have been least, and, conversely, that residuary soils least resemble their parent rocks when the chemical changes have been greatest. The stony material of the trap residuary, composed of half decomposed and thoroughly oxidized pieces of trap, often seem to be in excess of all the finer constituents.

Within the moraine, the ice sometimes failed to leave much drift on the trap ridges. Here there is little residuary material, since the time since the last ice incursion has been too short to effect deep disintegration of the rock. In general, the surface earths on the trap ridges are not of great depth.

Crystalline schist residuary earths.—Where the crystalline rocks are not covered with drift, and in some places where they are covered with drift of the earlier glacial epoch, the underlying rock is coated with a thick bed of residuary earth. Locally this is very stony. But where the schists are composed mainly of decomposable minerals, the

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* The distinction here suggested is perhaps an artificial one. Surface material arising from the decay or disruption of rock may be shifted about on a land surface by creep, and wind, and surface drainage, and after its movement and deposition on a land surface it still passes for residuary material, unless accumulated in considerable quantity along drainage lines. But if, after its shifting, the material be deposited beneath water, be it sea or lake, it is no longer regarded as residuary. That is, a different and a greater geological value is often set upon subaqueous accumulations, than upon subaërial. There is some reason for this distinction, but no reason for carrying it so far as is commonly done.

decomposition product is an arkose sand or loam, relatively free from bowlders of decomposition. The greater depth of the residuary material on the crystalline schists is an index of their more rapid decomposition, as compared with shale and trap, or of the less ready removal of the decomposition products. In many regions outside the moraine, even where the topography is rough, the rock is more or less uniformly and deeply mantled with the decomposed gneiss, the rock being rarely exposed. The general absence of gullies in the areas of crystalline-schist residuary soils and surface earths, indicates that their removal is slow. This is probably the result of their porous, arkose texture.

Commingling of residuary products.—In many situations it happens that the products of decomposition have been greatly mingled one with another. This is especially true where formations of different characters rise considerably above an intervening depression. In the depression, materials from the different surrounding formations may become much commingled. In such cases the recognition of the real nature of the surface materials may be difficult. They may closely resemble drift.

Along the junction of two formations, where the altitude of the one is considerably greater than that of the other, materials from the higher may be widely spread over the lower in the form of talus, sometimes completely concealing the lower formation for considerable distances along the base of the higher. Thus at the bases of the trap ridges, the products of the trap which have crept or been washed down the slope, often cover the red shale for considerable distances beyond the line of junction of the two formations. The same conditions exist where the crystalline schist adjoins the younger formations which lie at lower levels.

Probably the detection and differentiation of strictly residuary material is nowhere else so difficult as in areas south of the glaciated region in the eastern part of the state. Certain phases of the surface earths in the Cretaceous (or Tertiary) region, contain traces of the yellow gravel. These traces may be very meager, sometimes not appearing at all on the surface, but appearing in vertical sections where such can be found. The surface and sub-surface material in which these yellow gravel pebbles are imbedded is often altogether indistinguishable, except for the pebbles, from the strictly residuary material derived from the Cretaceous (or Tertiary) beds beneath. The pebbles, which are the only diagnostic mark of the re-arrangement and re-deposition of

the surface materials, as distinct from Cretaceous or Tertiary residuary, may be few or altogether wanting. Where the latter is the fact, the distinction between residuary earth and re-arranged material which is not strictly residuary may be most difficult. Where this re-arrangement of the gravel and its admixture with the Cretaceous (or Tertiary) sands and marls is the fact, it was accomplished during a period of erosion and re-deposition when the streams had cut through the gravel into Cretaceous (or Tertiary) beds below, or possibly during a period of submergence, after such erosion, when the oceanic waters aided in the process of mixture and re-arrangement. In some cases it seems probable that the unindurated formations may have been eroded, and the material re-deposited, without much transport, in essentially its original condition. Under such circumstances, the differentiation of the new and the old, and the differentiation of the new from strictly residuary material, is not easy, and perhaps not always possible.

SECTION XI.

THE YELLOW GRAVEL.

Apart from the work done by Mr. Coman, relatively little attention has yet been given to the "Yellow Gravel" formation, except where it comes in contact with drift of glacial age. In association with such drift, it has been more or less studied along the Delaware river, where the Trenton gravel adjoins and overlaps it, and along the borders of the Trenton gravel outside the valley of the Delaware. The sand and gravel of the overwash plain near Plainfield, corresponding in age with the Trenton gravel of the Delaware, likewise covers yellow gravel locally, and in one place, as already noted, a mound of the yellow gravel projects through the gravel of later (glacial) age. Remnants of the yellow gravel also occur low on the slopes of the trap ridge near Plainfield, but distinctly above the overwash plain.

Original northward extension of the yellow gravel.—Neither the time nor mode of origin of the yellow gravel formation is certainly known. Its original distribution, too, has never been determined, and possibly never can be with exactness. But enough is known to make it certain that its present distribution does not correspond at all closely with its original distribution. The remnants of the formation at and near Plainfield tell of its former northward extension much beyond the limit of its present continuous body. There is no reason to believe that the outliers at Plainfield mark its original northern limit. There are many reasons, both direct and indirect, for believing that they do not.

Scattered pebbles of yellow gravel have been found at a number of points on First mountain between Plainfield and a point ten miles further west. So far as known, there are no beds of this material on the trap ridge, and the pebbles which have been noticed above 200 feet are so few and far between, that in most cases it would seem as reasonable to suppose that they had been carried to their present position by human agency, as that they represent the remnant of a continuous formation which once reached far up the slope of the trap ridge. The pebbles which have been seen on First mountain occur only on its outer face. They have nowhere been seen on its summit, and in most places only on the lower half of the slope.

But for certain situations, the suggestion that the scattering, high-level yellow gravel pebbles owe their position to human transportation cannot be accepted. In one locality on the north slope of Second mountain, not far southwest of Union Village, and three or four miles north-northwest of Plainfield, pebbles which appear to belong to the yellow gravel have been found at an elevation of more than 300 feet, in in such situations and relations as to make their reference to human transportation impossible. Pebbles and small stones which have been referred with less confidence to the same formation, occur very rarely between First and Second mountains, especially between the western parts of these ridges. In all these situations the remnants are no more than exceedingly rare pebbles and cobbles, so rare that only the closest attention detects them.

Two miles or so west-northwest of Bound Brook a bed of yellow gravel, several feet thick, runs up to an elevation of about 120 feet. Due north of Somerville at an elevation of about 180 feet a bed of yellow sand containing some gravel occurs beneath a bed of coarse, till-like drift, on the south slope of the ridge.* The sand is very much like that belonging to the yellow gravel formation, and is tentatively referred to it. Again, just north of Raritan, at a slightly lower elevation, but on some of the highest elevations in the immediate vicinity, yellow gravel and sand occur. The deposit is here largely of sand, and pits of considerable extent have been opened in it.

Ten miles further north, and a half mile or so southeast of Peapack the material thrown out from a freshly-dug well (1892) was seen. From beneath a covering of other material (mainly talus) several feet in depth, quantities of bright, yellow sand had been thrown. The thickness of the sand was not known, but it was said to have been penetrated nine feet. The sand here seen agreed so closely in character with that near Raritan that it was impossible to avoid the conclusion that they are probably to be correlated with each other. The rock subjacent to the sand was not seen, but according to the geological map limestone lies beneath. It certainly occurs in the immediate vicinity. The elevation of the site of the well is about 240 feet, according to the topographic map.

A few miles east of Peapack, in the vicinity of Bernardsville and

* Professor Cook, whose eye few things seem to have escaped, noted the existence of the deposits here referred to, in 1880. He regarded them as preglacial in age. Geological Survey of New Jersey. Annual Report for 1880, pp. 86, 87.

Basking Ridge,* and especially in the west side of the ridge at Basking Ridge station, and in a neighboring elevation on the west, sand bearing much resemblance to that at Peapack is found in quantity. It is here somewhat less yellow, but is in places slightly arkose, and distinctly micaceous, qualities which the yellow gravel and sand to the southeast frequently possesses. These are just the qualities which might be expected in the vicinity of the crystalline schists. At both Peapack and Bernardsville, the yellow sand, while not on the crystalline schist, is very near its border. In the latter vicinity, the yellow sand rises to an elevation of 460 feet at least. There are certain beds of sand closely resembling that at Basking Ridge three or four miles further southwest, and about two miles west of Liberty Corner, at an elevation of about 400 feet.

Correlation.—While final conclusions concerning these beds of sand and gravel have not been reached, we believe there can be little doubt that the sand and gravel of the pit just north of Raritan (not including the uppermost part of the section), the sand and gravel under the till-like material north of Somerville, already referred to, and the sand at Peapack, are to be correlated with each other, and with the yellow sand and gravel at localities further south. We believe that the sands near Basking Ridge and west of Liberty Corner, are to be correlated with each other, but we are less confident that they are to be connected with those at Raritan and Peapack.

This tentative correlation involves a difficulty which we have not yet been able to explain away, in that it places the finer part of the yellow gravel formation to the north, against the highland, and the coarser part to the south. The reverse is the arrangement that would have been expected, though the materials of the yellow gravel do not appear to have been derived from the crystalline schists in any large measure.† We have no evidence to preclude the hypothesis that some of this yellow sand, as that at Bernardsville, may be much older than the yellow gravel has been supposed to be. Indeed, there are some considerations which seem to favor this view. So far as now known, nothing in the constitution or distribution of these

* Professor Cook made the suggestion that the beds of drift about Basking Ridge might have arisen in connection with Lake Passaic. But the elevation of the higher beds of drift in this vicinity seem too high to be connected with the last Lake Passaic, at least. Geological Report of New Jersey. Annual Report for 1880, pp. 84, 85.

† Op. cit., p. 95.

sands, lying far north of the main body of yellow gravel, puts any limitation upon their age, except that they be post-Triassic.

If the suggested correlation of these isolated beds of sand with the yellow gravel be correct, the yellow gravel formation once extended northward to the crystalline schist area at least, though we are not possessed of data which directly indicate that the First, Second and Third mountains were entirely covered by it. It is interesting to note, in this connection, that Prof. Davis long ago arrived at the conclusion that some formation younger than the Trias once covered the red shale, reaching northward approximately to the crystalline schist area. This conclusion was the result of a careful study of the present courses of the streams.* Prof. Cook also recognized the fact that the original northern border of the yellow gravel formation extended north of the Raritan,† though he does not appear to have associated the Basking Ridge sand with the yellow gravel and sand further south. It is possible that they should not be so associated.

Yellow gravel in the vicinity of Raritan bay.—On the low Triassic area south of the moraine and north of the Raritan, in eastern New Jersey, there are remnants of the yellow gravel to be seen at various points. It occurs beneath the glacial drift in the railway cut at Metuchen. It may be seen in much stronger development in the railway cuts a little further southwest. Traces of it occur at frequent points between Metuchen and the Raritan, and westward to Bound Brook. Southeast of Metuchen it frequently appears beneath the drift, and south of it, throughout the Woodbridge clay district, where elevations of the formation now and then project through the drift. It is exposed in very extensive pits at Bonhamtown, two miles southeast of Metuchen.

Within the Triassic area south of the moraine and north of the Raritan, the yellow gravel nowhere attains great elevations, though there are no heights above its reach. The highest lands of the region are likely to be strewn with it, and it forms a capping to many an isolated hill. But it is not confined to the heights, nor is it there thickest. At Bonhamtown the top of the pit is less than 100 feet in height, but there is here a greater depth of the gravel and sand than

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*The Rivers of Northern New Jersey, &c., by William Morris Davis. Nat. Geog. Magazine, Vol. II., No. 2, 1890.

†Op. cit., p. 88.

is known at any higher point north of the Raritan, in eastern Jersey. It is exposed to a depth of thirty feet.

South of the Raritan and east of the Millstone, traces of the gravel are likewise widespread over the red shale area, and considerable beds of it are not wanting. It may be well seen within the limits of New Brunswick. The high areas west of New Brunswick, in the vicinity of Voorhees, Clyde, and Middlebush, are covered with beds of it, often several feet in thickness, while the lower lands frequently have no more than a sprinkling of pebbles, and sometimes none at all.

Within the area between New Brunswick and Millstone, as well as at various points north of the Raritan, especially about New Durham, New Market and vicinity, there are large numbers of hard sandstone or quartzite stones, which have singularly angular forms. These stones are often scattered singly over the red shale surface. Their peculiar angular forms and minutely pitted surfaces are the result of the wear of sand driven against and over them by the wind. In many cases there is now no sand in their vicinity. Their forms show clearly enough that they have not suffered transportation and wear since they received their shaping. It follows that the sand which shaped them must have since been removed. The stones doubtless remain because they were too large for removal at the hands of the agencies which carried away the sand which shaped them. From the frequent association of these stones with the border of the overwash plain southeast of Plainfield, it is possible that last glacial sand may have been the tool which, in the hands of the wind, produced much of the wear on the angular wind-worn stones.

Southward distribution of the yellow gravel.—Still further south and east, beyond the limits of the Triassic area, the yellow sand and gravel formation has a very wide distribution. Concerning this point, Professor Cook wrote:

"This formation is not continuous throughout the southern part of the State, although it is found unconformably upon all the older strata of the cretaceous and tertiary ages. It is common on all the higher grounds, and forms the crests of the hills and ridges. The tops of many of the Mount Pleasant hills from Neversink highlands westerly, Arney's mount, in Burlington county, and the hills of the southeastern and the southern parts of the State are made up largely of this formation of drift. It is cut into at so many points on the lines of the New Jersey Southern, the West Jersey, the Camden and Atlantic and other railroads that it is not necessary to mention them

individually. In the greensand marl belt it is wanting over quite large areas, and it appears in small patches, but generally forming the hill tops or making slight swells in the surface. Southeast of that belt it is not found uniformly throughout the country, but in belts. It would seem as if it had been originally much more extensive, but the denudation of the surface and the drainage wash of the country has removed it from large areas."*

Vertical distribution of the yellow gravel.—Without further details concerning its areal distribution, reference will here be made to its occurrence at a few points where its position is especially significant. It is well developed in the vicinity of South Amboy, occurring at elevations of about 150 feet, on the highest lands in the vicinity. It is likewise present on the lowlands, having a vertical range nearly as great as that of the land relief. It is present on the Navesink highlands, points of which are more than 200 feet high. Three miles south of Matawan it occurs on the tops of isolated hills, the heights of which approach 400 feet, the highest points in this portion of the state.

At various points north of Freehold it occurs at heights of more than 170 feet. Four miles north of Farmingdale it occurs 300 feet above the sea, while west of Asbury Park and east of Farmingdale it occurs at elevations of nearly 200 feet, with a great vertical range. At many points not distant from those where the gravel occurs at considerable heights, traces of it occur at all levels down to fifty feet and less.

Where the gravel covers the hills, it generally has but slight thickness, rarely so much as twenty feet, often no more than three or four, while frequently only a trace of it remains. But these traces on the summits of the hills are full of significance as indicating the former extent of the deposit.

The general relations of the formation to the underlying beds is represented diagrammatically by the following figure:

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*Report of 1880, pp. 92, 93.

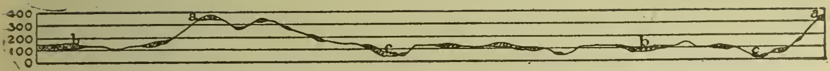

Fig. 9.

Diagram illustrating the theoretical relations of the yellow gravel formation; *a a* represents the original pre-Pleistocene yellow gravel, as here suggested (see. 1., p. 164); *b b* represents the general level to which the surface was degraded subsequent to the deposition of the oldest yellow gravel, before the first glacial epoch (see 2, p. 165). The gravel on the surface *b b* represents the gravel referred to later as the older phase of the secondary gravel and may be in part pre-Pleistocene (see 3, p. 165). The gravel on the low terraces at *c c* represents the second phase of the secondary gravel (see 5, p. 166). The numbers at the left of the diagram represent altitudes in feet.

From this distribution it will be seen at a glance that the yellow gravel, as it now occurs, is no simple or single formation. There is no known natural process by which gravel can be placed on the summits of isolated elevations such as are represented in the diagram.

Conjectured history of the yellow gravel formation.—There would seem to be two ways in which the gravel could have reached the position which it now occupies on these hills. In the first place it may have been deposited on an approximately level surface, of which the highest hilltops now covered with it, formed a part. On this hypothesis, the surface on which the gravel was deposited was probably beneath the sea. In this event we have, in the elevation of the remaining hills, a minimum measure of the amount of subsequent elevation. Since the elevation, rain and river erosion have so far worn away the sand and gravel, and lowered the old surface on which they were deposited, that only isolated points, represented by the high hills, remain to mark the horizon of the original formation.

The second possibility is not radically unlike the first. It would seem that hills might have been developed in the yellow-gravel country somewhat as now, before the deposition of the yellow gravel. If, then, the land sank, the depressions between the hills might have become filled. Conceivably this process might have continued until the depressions between the hills were built up to the level of the hills themselves, when gravel might have been laid over all. In this event, subsequent elevation or elevations brought the land to such a position that river erosion again became effective. The present irregular and hilly surface, with a relief of nearly 400 feet, is the result of this work.

Of these hypotheses, the first seems the more probable. Did the latter represent the sequence of events, it would not be likely to

happen that the present hills would always correspond in position with those which antedated the gravel deposition. Hills developed after the gravel was deposited, would be as likely to be developed between the earlier generation of hills, as elsewhere. If the second hypothesis were true the fact that none of the highest hills have more than a relatively thin covering of the gravel * could be accounted for only by supposing that the earlier generation of hills corresponded in position with those which now exist. The improbability of this supposition throws doubt on the hypothesis which involves it. Furthermore, the first hypothesis is much more simple, and so far forth more acceptable, if it explains the facts equally well. In either case it would seem that the gravel deposited at any given stage must have been deposited on a more or less inclined but nearly plane surface, for there is no known method by which water can carry gravel to the top of isolated hills, leaving the intervening regions relatively less deeply covered.

In any case, the gravel-covered surface was lifted subsequent to the deposition of the gravel. So soon as the rise brought the gravel above sea-level, rain and river erosion began their work. Gullies would be developed promptly so soon as the raised surface reached such an altitude as to give the drainage water passing over the surface any considerable fall. The gullies would presently have grown to the dimensions of valleys, and the streams, lengthening and widening and deepening their valleys as streams do, finally brought much of the surface to a level much below that which the elevation, if unopposed, would have given it.

If the gravel were deposited under the conditions indicated, its present distribution, apart from that which caps the hills and higher areas, is the result of the re-distribution and re-arrangement of its constituent parts in subsequent time. As valleys were excavated, gravel and sand from the original surface descended their slopes and accumulated along their bottoms. Wherever flood plains were developed, the gravel would be a constituent of them. If these plains were developed at different levels in successive stages of the history of the valleys, the gravel would be found at all these successive levels.

* Professor Cook is authority for the statement that the thickness of the formation reaches forty feet on the Mount Pleasant hills of Monmouth county, and possibly seventy feet on the highest of them. Such thicknesses as the latter have not come under our observation and are certainly exceptional. Op. cit., p. 93.

But in the secondary positions the yellow gravels should be found mingled with such other materials as were accessible to the rivers when the flood plains were being constructed. These other materials would have been derived from the sub-stratum of the gravel. And on much of the lower land where the gravel occurs, and in the terraces representing the old flood plains of the streams, the gravel is found to be thus mingled with finer materials, apparently derived from the sources indicated. In such situations the gravel is often a minor constituent, the finer materials, derived from the sands, clays and marls of the region, being in excess. Iron concretions, and masses of sand cemented by iron, derived from formations beneath the original yellow gravel, are locally abundant in the gravel in its secondary positions on the lower lands. The presence of the gravel on the lower lands would thus seem to be readily accounted for, and it certainly possesses many of the differential marks which would be expected of it in secondary positions.

There are some points in the distribution of the gravels which do not seem to fit this hypothesis. It would seem that the gravel should not be thicker on the lower lands in secondary positions, than on the higher lands in primary positions, and in general it is not. But it is certainly much thicker at some points on the lower than at most points on the higher lands, so far as now known; that is, it is often much thicker in its secondary than in its primary position. Possibly this fact calls for some modification of or addition to the simple course of events sketched above, though the modification need not be serious.

If, after much erosion had affected the original yellow gravel surface, the region where it occurs sank to such an extent that its lower parts were submerged, it is conceivable that very considerable thicknesses of gravel, derived from the original beds, might have accumulated along the margins of the submerged area, and these accumulations might have been relatively free from finer material which the waves might have carried to more distant points. This may be a possible explanation of the greater thickness of the material below the original plane of deposition. It is possible, too, that the original sources whence the oldest yellow gravel was derived, a second time yielded material for a newer formation, comparable in character with the first, or that a newer formation of yellow sand and gravel was derived from altogether independent sources. There is much reason to believe in a widespread but not deep submergence, long subsequent to the oldest

yellow gravel formation, and antecedent to the glacial epoch, when a second formation, which has been classed as yellow gravel and sand, was made, more sandy, more arkose, and more heterogeneous than the first.

Whatever may have been the details of the process, and difficult as it now seems to unravel its complications, the general fact seems to be clearly indicated that the uppermost gravel represents the original yellow gravel, and that the similar materials on the lower lands represent a younger formation, derived in considerable part from the older.

While re-distribution of the gravel began when the original formation began to suffer erosion, and has not ceased from that day to this, there are not wanting facts which seem to indicate that two somewhat distinct stages in the re-distribution, an older and a younger, may be recognized. These may perhaps be connected with the attitudes and altitudes of the land at two different periods.

The gravel which seems to represent the older stage of re-distribution covers those lands whose elevation, while distinctly below the summits, is still distinctly above the valley terraces and the corresponding lowlands about the coast, which are believed to represent the younger stage of re-distribution. The two types of surface here referred to are sometimes thoroughly distinct. In such cases the differentiation seems clear. But in other places, the slopes between them are gentle and broad, and all distinction seems to vanish. Mr. Coman, who has seen much of the yellow gravel formation in all its phases, has found it impracticable to carry out the suggested distinction.

In some places, that surface which represents what may be here designated the older secondary gravel, is generously strewn with bowlders. This is true a few miles southeast, south and southwest of New Brunswick, and to a less extent about South Amboy, as well as at many other localities not far south of the Raritan. At some localities north of the Raritan, as at Bonhamtown, the sand and gravel carry occasional bowlders. In all these cases the bowlders are predominantly of hard, compact, brownish-yellow standstone (Cambrian), while purplish quartzite (in part Green Pond Mountain) is the next most abundant constituent. But other types of rock are by no means wanting. At Bonhamtown, the writer has seen in the face of the open pit at least one trap bowlder, and several large pieces of red shale, one four feet in diameter. Trap and crystalline schist bowlders may rarely be seen both north and south of the Raritan.

The crystalline schist bowlders are generally rich in quartz and

poor in feldspar, a fact which has doubtless enabled them to resist the processes of disintegration. It is possible that bowlders of less resistant material may once have occurred in the same region in greater abundance than now, and that they have subsequently disappeared. No limestone bowlder has anywhere been seen in the region here described. In the absence of abundant deep exposures, it is difficult to say how far the apparent restriction of abundant bowlders to the surface may represent the real fact. The few deep exposures seen, as at Bonhamtown and Jamesburg, have not shown an entire absence, but certainly a scarcity of them, beneath the surface. Red shale masses especially, which are entirely wanting at the surface, are sometimes present below.

Trap, crystalline schist, Green Pond Mountain conglomerate, and red shale bowlders, so far as known, do not occur in the gravel which is here looked upon as the original yellow gravel formation. They occur in the older of the two secondary formations, where the above division seems recognizable, but are rare in the younger.

The presence of the bowlders, which are often ill-rounded, and sometimes altogether unrounded, suggests the co-operation of ice in the production of the beds containing them. Icebergs from an earlier ice-sheet, or possibly the ice-sheet itself of an earlier epoch, may have been concerned in the distribution of the bowlders. The decision as to which of these agencies was concerned cannot be said to be beyond question. But the size and local abundance of the bowlders, as well as their occasional glaciation, leave no room to doubt the co-operation of the one or the other. The character of the bowlders, as well as that of the gravel, seems to preclude any connection with the ice of the last glacial epoch.*

Yellow gravel and the Columbia formation in the western part of the state.—The yellow gravel occurs in the western, as well as the eastern part of the state. It is well developed near Trenton, and more or less continuously from Trenton to the region to which reference has been made. It occurs in the valley of the Delaware at Trenton, sometimes beneath the Trenton gravel. As the Trenton gravel thins out east of the river, the yellow gravel rises to the surface from beneath it.

*The abundance and great size of these bowlders, as well as their occasional glaciation, was referred to by Professor Cook in his Annual Report for 1880, p. 86.

The Delaware valley, therefore, must have been excavated to something like its present depth before the last glacial epoch. Into this valley the gravel from the surrounding country had been washed, if its original deposition antedated the excavation of the lower part of the valley, as is believed. On the other hand, if the valley were as deep as now, before the yellow gravel was deposited, the valley gravel might represent the original formation. As already indicated, we incline to the former hypothesis.

In the eastern part of the state the southern part of the glacial drift overlaps the northern border of the yellow gravel. To the west, the borders of the two formations, as now continuously developed, diverge widely from each other, the former running north of west, and the latter south of west. Over much of the area included in the angle between these two diverging lines there is a sprinkling of cobblestones, bowlderets and bowlders, the relationship of which is not altogether clear. They do not occur over the whole area, even sparingly. Considerable tracts of the extensive table lands north of Hopewell and northwest of Flemington appear to be free from them. On the south side of the table land north of Hopewell they appear to be limited in altitude, though because of their very scattered distribution, their upper limit is difficult of definition in advance of detailed work in the region. They occur locally to an altitude of 200 feet, and perhaps even higher. Referring to this area, Professor Cook said:

"It is not an entirely *driftless* area. There are a few deposits which have somewhat the appearance of glacial drifts, and which may mark the southern ends of lobes or tongues of ice stretching beyond the general or frontal line of the glacier. It is, however, more probable that they are deposits of local floods, especially as in all of them there are traces of stratification.

"Throughout the central part of the State small bowlders of hard rock, very smooth and round, are sparsely scattered over the surface. Stratified beds of earth, sand, gravel and small bowlders are found at very many localities. The latter are common on the lower grounds, and especially in the valleys of the larger streams. The bowlders are more widely distributed in the valleys and on the hills. Both of them appear to be deposits in water, transported by the currents of broad streams or carried on floating ice, and dropped with less assorting. The southern limit of the coarser drift and cobbles is defined by the valleys of Lawrence's brook and the Assanpink creek. South of the line there are few bowlders, whereas north of it to the terminal mor-

aine they are common. The greater part of this drift, including the smooth and well-worn quartzose bowlders and cobblestones, and the stratified beds of yellow sand and gravel, appear more like that in the southern part of the State, and it is an older glacial, or possibly pre-glacial, drift. But it is difficult to draw the line between it and the remaining part which came from the north and belongs to the modified glacial drift, except that much of it occupies a higher level. An incomplete series of observations upon the upper limits or distribution in height of the drift in this part of the State fixes the range between 350 and 500 feet in the Great Red Sandstone plain, and between 500 and 900 feet in the higher valleys and on the hillsides of the highlands. A submergence to this extent would have allowed icebergs and icefields to drop scattering bowlders and gravels, and would explain the position of these erratics. From the height of the gravels in Monmouth county it is evident that the submergence was at least 380 feet, if not much greater. And this seems to correspond with the drift line in the central part of the State and in the red sandstone district."*

We are inclined to think that the drift referred to in the preceding passage is not all to be classed together, and Professor Cook's language does not necessarily imply that he so regarded it. We believe (1) that the northernmost parts, occurring at the high altitudes, are glacial, and referable to an earlier ice epoch, and (2) that some of that further south is of equal age with the earlier glacial drift, but of aqueous or of aqueous and iceberg origin (the Columbia of McGee), while (3) still other parts are tentatively regarded as the equivalent of the yellow gravel formation, and older than the oldest glacial drift which has been thus far recognized. It is hoped that the differentiation of these types may be made clear in the future. What is now known seems to indicate that topographic and geographic distribution will probably make possible the distinction between the first and second classes, the aqueous and berg drift being restricted to lower altitudes and mainly to lower latitudes. Differences in distribution will probably not make possible the differentiation of the second and third classes.

It will be remembered that in the eastern part of the state the yellow gravel originally extended much further north than the limit of its present continuous development. The same was probably true in the west. The stony drift scattered over the surface for a few miles north of the main body of yellow gravel in the western part of the

* Op. cit., p. 81.

state, might, so far as its position is concerned, represent the remnant of a former northward extension of the yellow gravel, the finer parts having been carried away while the coarser remained. In the constitution of some of this drift, there is inherent evidence that such is its origin. The drift materials on the lower levels south of the glacial region, and north of the yellow gravel, are in kind very like the coarser materials which occur abundantly on the surface of the secondary yellow gravel, and in its upper parts in many places. This similarity suggests a genetic relation between the two. The topographic relations of the bowlders in the two classes of situations seem consistent with their contemporaneous origin, at a date long subsequent to that of the original yellow gravel formation.

Along the Delaware valley the type of drift here referred to has been regarded by Mr. McGee as belonging to the Columbia formation, the southern chronological equivalent of the first glacial epoch of the north. If the country were at this time so low as to submerge all that part of the State where this phase of the drift occurs, it might have been possible for icebergs to carry bowlders beyond the ice, distributing them as now known. The occasional glaciated surfaces observable on the bowlders seem to support this interpretation. If this be the correct view, the later part of the older of the two *secondary* phases of the yellow gravel is to be correlated with the Columbia. If the bowlders in the yellow gravel area were confined *to the surface of the older portion of the secondary yellow gravel*, they might have been distributed long subsequent to the development of the secondary yellow gravel surface on which they lie. In this event the Columbia formation is younger than the older of the two secondary formations of yellow gravel. Too little is known of the constitution of the deeper part of the secondary yellow gravel, to allow of positive conclusions on this point at present.

Summary.—If the last suggestion as to the relation of some parts of the stony drift on the Triassic area north of Trenton be the true one, the succession of events would be something as follows, commencing with the yellow gravel:

1. *The time of deposition of the original yellow gravel*, when the country was sufficiently low to allow the accumulation of gravel on lands which are now hills nearly 400 feet high (south of Matawan), and perhaps at equal elevations far north of the Raritan. Pre-Pleistocene.

2. *An epoch of elevation and extensive erosion,* during which the generally level surface of the yellow gravel was cut down from the altitude of the hills southeast of Matawan and Hightstown, an altitude of 350 to 400 feet, to the altitude of very considerable stretches of territory which now stands at from 120 to 150 feet. Above this lower level, hills of greater or less height were left standing. This epoch must have been of long duration.

3. *An epoch of depression,* during which central and southern New Jersey was lower than now by something like 150 feet, and when, therefore, most of that part of the state lying southeast of a line running from Trenton to Newark was submerged, as well as limited areas to the northwest of this line. With this amount of depression, certain areas south of the line indicated would have stood above the water as islands. Upon the surface thus submerged, the older phase of the secondary yellow gravel, or perhaps a new and younger yellow arkose sand and gravel formation, was spread. This interval of depression, or its later portion, may have corresponded with the first glacial epoch, when the ice coming down from the north calved its icebergs into the sea, whence they were floated widely over the southern part of the state and beyond, and dropped in the situations where they are now known to occur. These bowlders may have been more or less deeply imbedded in what was the surface material of the submerged area, according to the strength of the waves and the amount of shore wash. The deposits made by this sea are perhaps to be regarded as Columbia, equivalent in age with the first glacial deposits.

4. *An epoch of elevation and erosion,* during which the height of the land was greater than before, and when the streams, therefore, were able to cut their valleys to greater depths than during the earlier epoch of elevation, perhaps to depths comparable with those of the present. During this process, the degradation and re-distribution of the remnants of the original (pre-Pleistocene) gravel formation went forward, at the same time that the secondary (Columbia?) gravel was suffering erosion and re-distribution. The erosion which took place during this interval was much less extensive than that of the preceding epoch of elevation. This may mean a shorter interval of time, or it may mean that the Columbia surface was much less elevated above the sea than was the original yellow gravel surface in pre-Columbia time, when it suffered its greatest erosion.

An epoch of slight depression, during which the deposits at some points above the coast, and along the lower courses of rivers, were made, from which the low stream terraces have been subsequently developed. This may have corresponded in time with the last glacial epoch, when the land may have been so low as to allow of the passage of water from Raritan bay to Trenton, but it more probably antedated the last glacial epoch.

6. *Subsequent elevation* to the extent of forty to sixty feet or more, accompanied by rejuvenation of the streams, followed by present subsidence.

The foregoing suggestions as to the sequence of events are not to be looked upon as a final judgment in the matter. It is no more than a tentative hypothesis of the sequence of events in central and southern New Jersey since the time of the original yellow gravel formation. It is not an hypothesis, however, which has no facts to support it. Many facts are now known which seem to be explained by it. There are some which, while not explained by it, do not militate against it. There are others which, at first thought, do not seem to favor it. It is possible that in the future data fatal to it may be found. But no such facts are now known to the writer, and the hypothesis is here suggested for the sake of the criticisms and suggestions which its publication may elicit. We believe that the full history will be found to be more complex than that here sketched. The stage here represented by 3 will probably be found to be divisible into at least two phases.

No affirmation is made concerning the date of the original yellow-gravel formation, except that it is pre-Pleistocene and that it antedates the first glacial epoch by a long interval of time. The relative amount of erosion which different formations have suffered is not always a safe criterion for estimating their relative age, even when the formations are similar in kind, and therefore equally erodable. The rate of erosion is so largely dependent on altitude, attitude, climatic conditions, and relations to the sea and to large rivers, that any judgment based upon the relative amounts of erosion must be lightly held. But on this basis, if judgment were to be expressed concerning the age of the original yellow gravel, it would be to the effect that its origin was more remote from the beginning of the Pleistocene, than the beginning of the Pleistocene is from the present.

PART II.

A PRELIMINARY REPORT

ON THE

Cretaceous and Tertiary Formations

OF

NEW JERSEY.

BY

WILLIAM BULLOCK CLARK.

A PRELIMINARY REPORT ON THE CRETACEOUS AND TERTIARY FORMATIONS OF NEW JERSEY,

WITH ESPECIAL REFERENCE TO MONMOUTH AND MIDDLESEX COUNTIES.

BY WILLIAM BULLOCK CLARK.

INTRODUCTION.

An investigation of the coastal series of New Jersey was commenced by the writer in the autumn of 1891, and continued during the spring and early summer of the present year. On account of the great distance of the region from the place of other and primary duties, it was not until late in May that continuous and systematic work could be undertaken, and this had to be finally abandoned toward the end of July. The investigations in the autumn of 1891 and during the spring of the present year were largely for the purpose of acquiring a knowledge of the general relations of the strata, and, if possible, of establishing sections at various points which would afford a basis for the ultimate correlation of the different horizons. With this object in view, numerous lines of natural exposure along the larger streams which cut at right angles to the strike of the strata were followed, and the distinguishing characteristics of the various layers noted, both from a lithological and palæontological standpoint. This was continued at short intervals from the northern to the southern end of the marl belt, before detailed work was undertaken at any point.

The reconnoissance of the region having been completed late in May, detailed mapping was commenced in the vicinity of Freehold.

This point was chosen partly from its central and accessible situation in the marl region, but more especially because of the distinctness of the stratigraphy, occasioned by the broken character of the country to the north and west of the town.

From this time on the writer had associated with him Messrs. C. W. Coman and H. S. Gane, the latter of whom had aided at times during the preceding spring and autumn. Both continued till the close of the field work in July, and rendered most important service, acknowledgments for which are cordially given at this time.

The region mapped covers the United States Geological Survey Atlas Sheets of New Brunswick and Sandy Hook, about 400 square miles in all, exclusive of the water area. This tract is chiefly confined to northern Monmouth county, though portions of eastern Middlesex are also included. It is planned to continue the work in the same manner throughout the remainder of the Cretaceous and Tertiary area of the State as rapidly as possible.

A new nomenclature has been adopted for some of the divisions of the series, as will be observed upon an examination of the text. The new terms employed are taken from localities where extensive and typical sections are found, and the reason for their use will be readily understood by referring to the text and map. The value of the old terms will be in all cases explained in the light of the new and the equivalents given. The use of lithological names, which are often deceptive, has been continued for most of the divisions, since they have been so generally employed by earlier writers on stratigraphical grounds. It may seem advisable, however, after a fuller study of the region, to replace many of these confusing terms by place names, but for the present the old nomenclature is disturbed as little as possible.

The preliminary report will deal largely with the distinctly marine phase of the Cretaceous, since it is that division of the series under consideration which is most characteristic of the coastal portion of New Jersey. It is composed of formations that in the past have been a source of great economic wealth to the State, and to-day condition to a large degree the limits of its richest agricultural region.

Each separate deposit of the Cretaceous-Tertiary series has been viewed too much in the past as an individual accumulation without reference to its relations to the entire sequence of deposits of which it is a part. The close interdependence of the different horizons has never been clearly pointed out, since surface differences of color and

texture have often caused sharp distinctions to be made that upon stratigraphic grounds are not warranted. Secondary changes, too, have caused so extensive an alteration of the deposits over wide tracts, along their thinned-out edges, as to render the separation of the various members of the series oftentimes very difficult.

The publication of the topographic sheets has for the first time made it possible to accurately delimit the formations of the eastern portion of the State. Found, as they are, dipping slightly eastward and with a line of strike that changes but slightly from a continuous trend, the limits of each horizon can be approximately mapped, even if largely obscured by later deposits. This form of mapping must naturally be conducted with great care, but where frequent outcrops are found, as was the case in the area examined, lines of almost absolute accuracy may be drawn. Throughout the more hilly country of the central and northern portions of the marl area the outcrops are much more numerous that toward the south, where the unbroken character of the region renders it often difficult over wide areas to definitely determine the limits of the various horizons. But for the artesian well-borings, now so common throughout this portion of the State, great uncertainty would prevail over wide tracts. In conducting these investigations particular attention has therefore been given to the records of well-borings. The State Survey has at all times carefully collected information of this character, and it will be found invaluable in unravelling the detailed stratigraphy of the Cretaceous-Tertiary region.

Borings to the depth of thirty feet have been made by the writer and his assistants at many points, so that the contact of the various horizons has been frequently determined where natural exposures were not to be found. This method proved to be of the very greatest importance in the prosecution of the mapping, and rendered it possible to carefully control results in an area of limited outcrops. The boring apparatus used consisted of a common wood auger, one and one-half inches in diameter, welded to a rod three feet in length. At its upper extremity a thread was cut which would fit into ordinary half-inch gas-piping. The latter, in lengths of three feet each, were employed to the number of ten. It was not generally found to be advantageous for several reasons to attempt to go below thirty feet. A rod of iron of the same size was used as a cross-bar, and except when coarse gravel or indurated layers were struck very little force was needed by the operator to propel the auger downward. The pieces of piping were

quickly attached by means of ordinary gas-pipe wrenches, so that the cross-bar could always be kept within easy reach of the operator. A simple lever was devised by means of which the rod could be readily withdrawn from the boring. Only occasionally, and in certain deposits, was the use of the auger impracticable. Several inches of the materials penetrated could be obtained from the boring at each removal, so that the determination of the deposit was generally a simple matter. The boring machine was regarded as one of the most important aids in the work and scarcely a trip was made into the field without it. Information was gained that would have been impossible except by tedious digging.

In the succeeding chapters of the report will be found an historical sketch, in which the opinions of past workers in this field will be briefly cited; an outline of the topography; and a statement in regard to the stratigraphy, in which the lithological and paleontological characteristics of the several horizons will be discussed. A final chapter of considerable length will be devoted to a discussion of the origin of greensand. Its distribution upon the floor of the present oceans, and during past geological time, will be considered, together with the theories that have been advanced to account for its formation. The result of the observations of the Challenger expedition will be particularly dwelt upon, and the New Jersey greensand deposits explained in the light of recent research.

HISTORICAL SKETCH.

The accessibility of the area, and the interest attaching to the marl deposits, early attracted the attention of geologists to the coastal region of New Jersey. The earliest of American geological writings refer to the territory under discussion, and few portions of the country were more often visited for scientific investigation. The first important contribution to American geology, made by William Maclure * in 1809, mentions the region, though in this publication the entire coastal plain is referred to the "alluvial formation," the fourth of the grand divisions of the geological column, according to the Wernerian classification which Maclure adopted.

Maclure subsequently revised and enlarged the work, which

*Am. Phil. Soc. Trans., Vol. 6, 1809, pp. 411-428.

appeared in book form in 1817, and in the Transactions of the American Philosophical Society * for the same year.

In a paper by Samuel Ackerly, † published a few years subsequent to Maclure's articles, the "alluvial deposits" of northern New Jersey are discussed in greater detail. In this paper the marl beds, together with their fossils, are referred to, but no evidence is adduced that the author recognized their taxanomic position.

In an article by James Pierce, ‡ published in 1823, there is a description of the marl district of Monmouth county. The general topographical features of the region are referred to, while the extent of the marls, and the uses which they serve as fertilizers, are mentioned.

By far the most important contribution to the stratigraphy of the coastal plain, that had up to that time appeared, was made by Prof. John Finch,§ in a "Geological Essay on the Tertiary Formations in America," in the American Journal of Science and Arts for 1824. This was the first attempt at a correlation of the deposits of the coastal plain on scientific grounds, and although thus early in the history of the subject, minute comparisons, which are always unsatisfactory, were made, yet the knowledge of American coastal formations was materially advanced. He states that much which has been called "alluvial deposits," by previous authors, is identical and contemporaneous with the newer Secondary and Tertiary formations of France, England, &c. He considers the New Jersey deposits under the name of the "Plastic Clay and Sand Formation" and the "Ferruginous Sand."

In notes by Lardner Vanuxum,|| arranged by Dr. S. G. Morton for publication in the Journal of the Academy of Natural Sciences, of Philadelphia, the attempt is made to more accurately delimit the "Secondary, Tertiary, and Alluvial formations of the Atlantic coast." The New Jersey strata are taken up for consideration and the marl deposits mentioned.

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*Am. Phil. Soc. Trans., new series, Vol. 1, 1817, pp. 1–9.

†An Essay on the Geology of the Hudson River and the Adjacent Regions, &c, New York, 1820.

‡Notice of the Alluvial District of New Jersey, with remarks on the application of the rich marl of that district to agriculture. Am. Jour. Sci., Vol. 6, pp. 237-242, 1823.

§Am. Jour. Sci., Vol. 7, 1824, pp. 31-43.

||Philadelphia Acad. Nat. Sci. Jour., Ser. I., Vol. 6, 1829, pp. 59–71.

During the years 1830–33 Dr. S. G. Morton published in the American Journal of Science and Arts a series of articles entitled "Synopsis of the Organic Remains of the Ferruginous Sand Formation of the United States, with Geological Remarks," in which the deposits and fossils of the New Jersey marl belt are especially considered. Other articles appeared by the same author in the publications of the Philadelphia Academy of Natural Sciences, while a special work embodying his results upon the same subject appeared in 1834.

The first official reports upon the geology of New Jersey were prepared under the direction of Prof. H. D. Rogers, and publications appeared in 1836 and 1840. In the first report the formations of the eastern portion of the State are divided into the Tertiary and Upper Secondary. Although the marls are recognized and described with some fullness, their differentiation into different beds was not attempted. In the final report for 1840 a section is given, from Princeton to Little Egg Harbor, of the Coastal Plain series in accordance with the views of the writer. In this section the basal member is classed as "Clays and Sands." Overlying this is "Greensand," while above that to the eastward is "Ferruginous Sand." Overlying the "Ferruginous Sand" locally is "Brown Sandstone." In the text there is another division, not shown in the section, which is interposed between the "Greensand" and "Ferruginous Sand" and known as "Limestone." These five divisions constitute the "Greensand Formation" shown upon the map that accompanies the volume. Although the various members are not clearly defined and widely different materials are included under the same division, yet the easterly dip of the strata was observed and the broader distinctions in the stratigraphy of the area were recognized.

The visit of Sir Charles Lyell to America in 1841, during which he examined the strata of eastern New Jersey, did much for the progress of geological investigations upon the Cretaceous and Tertiary formations. Lyell made numerous comparisons of the New Jersey strata with similar deposits in other portions of this country and of Europe.

A second official survey was inaugurated by the State under the direction of William Kitchell, and annual reports were published for the years 1854, 1855, and 1856. The formations of the eastern portion of the State were described by the Assistant Geologist, George H. Cook, who was later to become the head of the present Survey, and in

that capacity to add more to the geological knowledge of the State than any other who had preceded him. In the first of these reports Prof. Cook recognizes that "there are three distinct beds of marl," a decided advance over previous knowledge of the marl district. These three marl beds were examined by him with much care and the characteristic features of each portion of them described in the reports which he presented.

During the decade 1860–70 many special articles appeared, the majority of them dealing with the paleontology of the several formations under consideration. Conrad, Cope, Marsh, Credner, Gabb, Meek, and others contributed to this end, so that with the later work published and in press we have a fuller knowledge of the fossils of New Jersey than of any other district in the Atlantic Coastal Plain.

Appointed State Geologist, Prof. Cook presented a report of progress for 1863, and every subsequent year, until his death in 18~~94~~, 89 reports were published, in which the investigations of a lifetime are found recorded. Closely associated with him in much of this work was Prof J. C. Smock, the present head of the Survey. It is unnecessary at this time to review the advance made each year, or to refer in detail to each report. In 1868 a large volume appeared, entitled "The Geology of New Jersey," in which an extensive description of the Coastal Plain deposits is found. In this report the Cretaceous is divided as follows:

Upper Marl Bed	Blue Marl. Ash Marl. Green Marl.
Yellow Sand	
Middle Marl Bed	Yellow Limestone and Lime Sand. Shell layer. Green Marl. Chocolate Marl.
Red Sand	Indurated Green Earth. Red Sand. Dark Micaceous Clay.
Lower Marl Bed	Marl and Clay. Blue Shell Marl. Sand Marl.

Clay Marls............... { Laminated Sands. / Clay containing Greensand.

Plastic Clay............. { Lignite. / Potters' Clay. / Lignite.

The marls of Shiloh and Jericho are referred to the Miocene, as well as an astringent clay that is found at many points to the east of the greensand belt, though there is some doubt expressed as to the age of the latter. An extensive discussion is given of the composition and use of greensand as a fertilizer, and in the appendix is a list of the fossils found in the Cretaceous. In 1878 a report on the clays was published, in which the district contiguous to the Raritan river at Amboy and Woodbridge is principally described. Just previous to his death, Prof. Cook had commenced the publication of a series of final reports, but nothing especially relating to the geology of the State had appeared, although Volume I. dealt with the topography, and thus, of necessity, the character of the underlying strata had to be briefly considered. Several volumes upon the paleontology on the coastal plain formations in New Jersey are in preparation by Prof. R. P. Whitfield, and two have already been published, viz., the "Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey," and the "Gasteropoda and Cephalopoda of the Raritan Clays and Greensand Marls of New Jersey."

In 1884 Professor Angelo Heilprin published an important work, entitled "Contributions to the Tertiary Geology and Paleontology of the United States," in which the coastal deposits of New Jersey are considered.

The boring of the artesian wells at Atlantic City called out articles by Mr. Lewis Woolman and Prof. Heilprin in the Proceedings of the Philadelphia Academy of Natural Sciences for 1887, which are important for the added data presented upon the extent of the Miocene in New Jersey.

Within the past year three general works dealing respectively with the Cretaceous,* Eocene,† and Neocene‡ of the United States have appeared in a series of Correlation Essays prepared under the auspices of the United States Geological Survey. In each of these works the

* By C. A. White. † By W. B. Clark. ‡ By W. H. Dall.

authors have given a review of all that had been published down to the date of writing, and in each instance the deposits of New Jersey are fully considered.

TOPOGRAPHICAL FEATURES.

The region discussed in the succeeding pages is a part of that great area of lowland bordering the Atlantic coast of North America and known as the Coastal Plain. It extends with constantly narrowing limits from the South Atlantic States across New Jersey, beyond which its continuity is broken, although represented in Long Island and other smaller land areas situated farther to the northeastward.

In New Jersey it is confined between the Atlantic ocean and a line passing up the Delaware river to its great bend at Trenton, and thence approximately following the direction of the Pennsylvania railroad to the vicinity of New York bay.

It comprises about 4,400 square miles, one-third of which is less than 50 feet above sea level. But little over a quarter of the area is above 100 feet, and only fifteen square miles exceed 200 feet in elevation. The highest point is found to the south of Keyport and reaches 391 feet.

This plain slightly exceeds 100 miles in length and varies in width from twenty miles in the north to nearly sixty in the south.

It is entirely surrounded by tidal waters, except for the twenty-eight miles from Trenton to the Raritan, where the height of the land, however, nowhere exceeds eighty feet. That elevation is reached at Monmouth Junction, on the divide between the waters which flow to the Raritan on the north and to the Delaware on the south.

The area, as a whole, is characterized by broad stretches of lowland which represent portions of a once continuous plain that has lost its level surface, due to the effects of erosion produced by the natural drainage of the land. On the northern and western sides the plain has suffered more largely than to the southeastward, and new levels and deeper stream channels have been opened. An area of highland, which I shall call the Highland range, stretches across this portion of the State from the vicinity of Sandy Hook to the head of Delaware bay, and forms the divide between the streams entering the Atlantic ocean on the east and the Raritan and Delaware rivers on the west. Beginning in the prominent headland of the Highlands of Navesink,

which rise to 269 feet, it extends westward as a clearly-defined ridge (south of Keyport reaching a height of 391 feet) for a distance of about fifteen miles, to the vicinity of Morganville, beyond which the range broadens and, with a general elevation of 200 feet, extends southward to Freehold. From this point the ridge turns to the southward

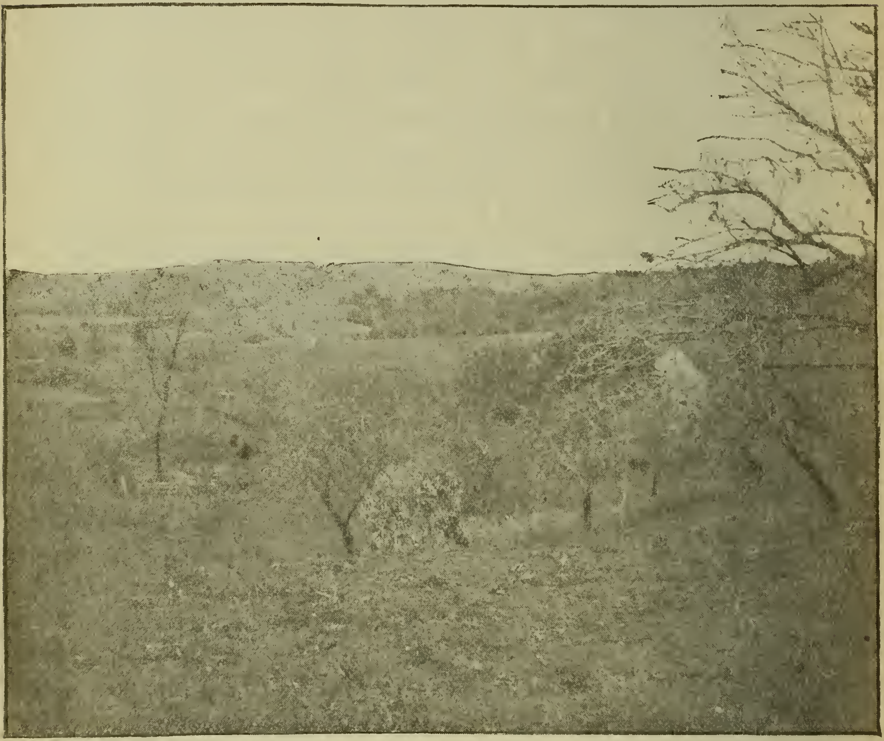


Fig. 1.
View among the Navesink Highlands.

as far as Clarksburg, in the vicinity of which is a group of hills more than 300 feet in height, the highest, Pine hill, being 372 feet above sea-level. From here the height of land extends southward, past Whitings and Woodmansie, with an elevation generally exceeding 150 feet, but seldom reaching 200 feet.

From Woodmansie, the divide runs slightly south of west, for a distance of about twenty-five miles, to the vicinity of Berlin, on the

Camden and Atlantic railroad. For more than a half of this distance the water-shed is depressed below 100 feet, reaching in one place eighty-five feet. It forms the lowest portion of the whole divide, and the Rancocas creek and Mullica river, which drain on either side to the Delaware river and the Atlantic ocean respectively, mark the most depressed belt of lowland crossing southern New Jersey. To the north of Berlin and near Clementon, the highland reaches a height, in two hills, of more than 200 feet, the last portion of the divide to attain that elevation. From Berlin, southwestward to Glassboro, the water-shed does not vary much from 150 feet in elevation, although a wide extent of country in this portion of the State reaches 100 feet above tide. From Glassboro, the divide extends more nearly south to the head of Delaware bay.

Numerous spurs extend outward from the main divide, separating, on the one side, the various streams that enter the Atlantic ocean, and on the other, the several tributaries that enter the Raritan and Delaware rivers. Among the more noticeable of these spurs of highland on the ocean side may be mentioned the ridge which extends nearly due east from Freehold, and which, less than a mile from Asbury Park, has an elevation of 184 feet. The most prominent of all the minor ridges is that extending southeast from Woodmansie toward Barnegat, and having an elevation of 154 feet not far to the west of that village. Another spur extends down the line of the railroads to Atlantic City. Other branches of the main divide, with an elevation exceeding 100 feet, extend southward to beyond Vineland, on the spur between the Great Egg Harbor and Maurice rivers, and to Woodruff, on the spur between the Maurice river and Cohansey creek.

On the westward side of the main divide, there are fewer prominent spurs, as the streams are smaller in size. Extending to the northwest, from the group of hills near Clarksburg, is a ridge of highland which forms the divide between those tributaries of the Raritan and Delaware rivers which have their rise in the Coastal Plain. To the west of New Egypt, is an area of highland that is quite encircled by the tributaries of the Crosswicks and Rancocas creeks, although smaller streams that reach the Delaware directly take their rise upon its western border. To the southward the spurs form a less prominent feature in the topography, although in some instances, as in the case of the divide between Raccoon and Oldman's creeks, maintaining an elevation of over 100 feet for several miles.

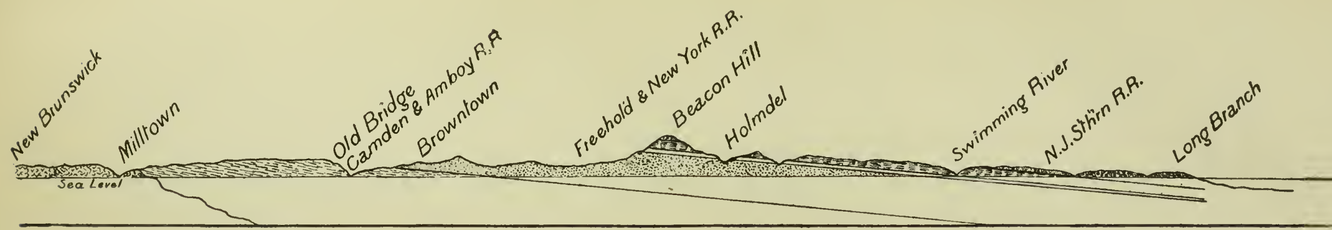
That the streams flowing to the southwestward into the Atlantic ocean differ in a marked degree from those that drain to the northwestward has been pointed out by Prof. Cook. The valleys of the Atlantic drainage are broad and level, the land rising gently on either bank, while the channels of the streams flowing into the Delaware have much steeper slopes, and are generally U-shaped. An explanation for this will be found upon an examination of the stratigraphy of the region, since the strata dip slightly to the southeastward, so that the streams flowing in that direction follow the slope of the beds, while those flowing to the northwestward must cut across their upturned edges. As the strata vary in hardness the widening of the channel must be retarded by the hardest layers. A fuller account of this subject is given by Prof. Cook in Volume I. of his final reports of the Geological Survey of the State.

STRATIGRAPHICAL CHARACTERISTICS.

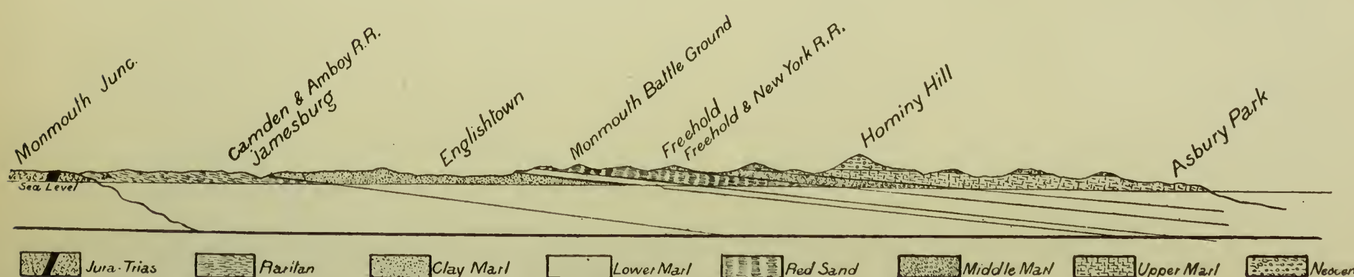
The Coastal Plain formations of New Jersey extend in a general northeast and southwest direction across the State. Their deposits and fossils present the same general characters throughout the area, so that the lithological divisions, established by Prof. Cook chiefly upon investigation in the north, apply almost equally well to all portions of the State. It has been the aim of the writer to hold as closely as possible to the nomenclature established by Prof. Cook, as it does not seem advisable at present to introduce new terms which would confuse the general reader. A few changes of importance in the general divisions of the series have, however, been rendered necessary, the grounds for which will be presented in subsequent pages.

In the following table the various divisions of the Coastal Plain series of New Jersey are given in accordance with the views of the writer:

Pleistocene.		
Neocene		Miocene.
Eocene	Shark River Marl	Upper Marl Bed.
Cretaceous	Manasquan Marl	
		Middle Marl Bed.
		Red Sand Formation.
		Lower Marl Bed.
		Clay Marl Formation.
		Raritan Formation.
Jura-Trias.		



SECTION FROM NEW BRUNSWICK TO LONG BRANCH.



SECTION FROM MONMOUTH JUNCTION TO ASBURY PARK.

PLATE III.

RARITAN FORMATION.

The term Raritan, employed as the distinctive name of this formation, is one which has been so long used by Cook, Newberry, Smock and others, for a greater or less portion of the series under consideration, that its retention and wider application seem fully warranted. The more recent investigations of Prof. Lester F. Ward, to be shortly published, show, however, a much closer relationship between the leaf-bearing beds of Amboy, Woodbridge and neighboring places and the Potomac formation of Maryland and Virginia than has been hitherto supposed to exist, and upon these grounds the inclusion of the deposits in that division seems to be indicated. Until more complete connection can be shown, however, between them, both stratigraphically and palæontologically, it seems to the writer inadvisable to definitely refer them to the same formation. The term Plastic Clays, employed hitherto by the State Geological Survey, is so inadequate an expression for the formation under consideration that it is abandoned, although the limits assigned by Prof. Cook to that division are very nearly the same as those given to the Raritan formation.

The width of outcrop covered by the Raritan deposits is estimated at about eight miles in Middlesex county in the vicinity of the Raritan river, where the strata are best exposed. Beyond Trenton, they include only a narrow belt along the right bank of the Delaware river, the chief development of the formation here being found in Pennsylvania.

The strata unconformably overlie the red shales of the Jura-Trias. They consist largely of clays and sands, many of them of great economic value. In the Report of the Clay Deposits published by the State Geological Survey in 1878 a detailed section, combined from all the available exposures in the worked district, is presented, and is reproduced here, as affording the most accurate sequence of the chief deposits of the Raritan formation available at the present time. Many of the strata, particularly the sandy beds, change in thickness and texture quite rapidly, so that the section can only be considered as typical within narrow limits. There is no natural section that shows more than a quarter of the entire series.

COLUMNAR SECTION OF THE RARITAN FORMATION.*

Sand and sandy clay, with lignite beds	50 feet.	
Sandy clay and sand	40 "	90 feet.
Stoneware clay bed	30 "	120 "
Sand and sandy clay	50 "	170 "
South Amboy fire clay bed	20 "	190 "
Sandy clay	3 "	193 "
Sand and kaolin	10 "	203 "
Feldspar bed	5 "	208 "
Micaceous sand bed	20 "	228 "
Laminated clay and sand	30 "	258 "
Pipe clay (top white clay)	10 "	268 "
Sandy clay	5 "	273 "
Woodbridge fire clay bed	20 "	293 "
Fire sand bed	15 "	308 "
Raritan fire clay bed	15 "	323 "
Sandy clay, with lignite	4 "	327 "
Raritan potter's clay bed	20 "	347 "

An examination of the sections in the vicinity of the Raritan river shows a preponderance of clays in the lower, and of sand in the upper half of the series. No unconformity is found at any point beyond the base of the series which rests on the Jura-Trias, although the individual beds of sand often meet along sinuous lines and exhibit frequent instances of cross-bedding. It is difficult to assign a limit to the upper portion of the series, since no unconformity occurs, and similar deposits are found in the overlying or Clay Marl formation. The conditions undoubtedly changed gradually. Alternating beds of clay and sand were formed during the transition stage, before the distinctly marine phase of clay marl deposition began. The strata are undisturbed in the main, having been bodily elevated in the epeirogenic movements that have produced the Coastal Plain. They appear to lie very nearly horizontal, but careful estimates that were made by Prof. Smock, in preparing the report on the clays, show that the lower beds have a dip of about sixty feet to the mile, which is gradually lost in the overlying strata, until, at the horizon of the stoneware clay bed, it is hardly thirty feet to the mile. It is possible that much of this may be due to difference in the original planes of deposition produced by sedimentation. The strike of the strata is about N. 50° E.

The fossils described from the Raritan formation are chiefly of

* Report on the Clay Deposits, 1878, p. 34.

plant origin, and consist, both of leaf impressions and lignite. Prof. J. S. Newberry * published a preliminary account of this flora in 1886, since which time until his death he had in preparation an exhaustive monograph upon the subject. More recently, Prof. Ward has taken up a study of the same flora, and has instituted comparisons with the forms from more southern localities, and finds a much larger percentage of species identical with those from the Potomac and Tuscaloosa formations, than has been hitherto supposed to be the case. We may thus, in these several formations, be dealing with deposits of contemporaneous origin, but more extensive study is necessary to finally establish that conclusion.

Some years ago Prof. L. Lesquereux examined specimens of leaf impressions from the Raritan formation, and identified several forms with those from the Dakota formation of the interior. Prof. Newberry, who has more fully examined the flora, corroborates the same. In his excellent essay upon the Cretaceous of North America, Dr. C. A. White states † that Prof. Newberry has identified 150 species of fossil plants from the Raritan formation, of which 120 are angiosperms, 5 are conifers, 12 are ferns, and 2 are cycads, and he considers that they afford "intrinsic evidence of Cretaceous age." He further places them at the base of the Upper Cretaceous.

Invertebrate fossils, particularly, are very rare. Dr. T. A. Conrad,‡ in 1868, described two species of shells, and in 1886 three more were added by Prof. R. P. Whitfield. § They are:

Astarte veta Conrad.
Corbicula emacerata Whitfield.
Gnathodon tenuidens Whitfield.
Ambonicardia Cookii Whitfield.
Corbicula annosa Conrad.

Since the specimens obtained have all been casts, Prof. Whitfield says "the generic characters of all of them are obscure, and cannot be positively affirmed, as their interiors are unknown. They would seem to represent *Gnathodon, Astarte* and *Corbicula*, and the one most common, a new genus, which I have called *Ambonicardia*." They are all brackish-water types.

The character of both deposits and fossils indicates shallow-water

* Torrey Bot Club Bull., Vol. 13, pp. 33-37.
† U. S. Geol. Surv., Bull. 82, p. 94.
‡ Am. Jour. Conch., Vol. IV., p. 279, pl. xx., figs. 4, 5.
§ U. S. Geol. Surv. Mon., Vol. IX., pp. 22-28, pl. 11., figs. 1-14.

accumulation and the prevalence of strong currents, which, at times, bore large quantities of the coarser sediments, since sand and even gravel occur. The invertebrate molluscan life points to brackish water, perhaps estuarine conditions, for a portion, at least, of the strata. The presence of greensand so common in the deposits of the succeeding periods, necessitating deeper water conditions, has not been observed in the Raritan strata. It has been a subject of frequent discussion how these deposits of sand and clay, which border the Jura-Trias, and yet were not derived from it, were formed.

The character of the materials shows that they must have been largely derived directly from the crystalline rocks. As the Raritan formation does not come in contact with such rocks along its western border, it has been frequently suggested in the past that an area of crystallines must have existed to the eastward, to afford the materials for the deposits in question. A study of the drainage of the Jura-Trias belt which separates the Raritan formation to-day from the area of crystalline rocks beyond, is of interest in showing the probable extension of the basal member of the Coastal Plain series quite over the red shales of the Jura-Trias to the border of the crystalline region, and at the same time affords a sufficient explanation for the absence of sediments derived from the Jura-Trias itself.

Prof. W. M. Davis * has recently presented the evidence for this wide extension of Raritan sediments in an article in the National Geographic Magazine. Although not claiming that the explanation offered is conclusive, he presents a series of deductive tests that seem fully warranted by the facts as shown by the streams that cross the Watchung mountains, "the curved edges of two great warped lava-flows of the Triassic belt. The noteworthy feature of this district is that the small streams in the southern part of the crescent rise on the back slope of the inner mountain and cut gaps in both mountains in order to reach the outer part of the Central Plain. If these streams were descended directly or by revival from ancestors antecedent to or consequent upon the monoclinal tilting of the Triassic formation, they would not possibly, in the long time and deep denudation that the region has endured, have, down to the present time, maintained courses so little adjusted to the structure of their basins. In so long a time as has elapsed since the tilting of the Triassic formation the divides would have taken their places on the crest of the trap ridges and not

* Nat. Geog. Mag., Vol. 11, No. 2, pp. 1–30, 1890.

behind the crest on the back slope. They cannot be subsequent streams, for such could not have pushed their sources headwards through a hard trap ridge. Subsequent streams are developed in accordance with structural details, not in violation of them. Their courses must have been taken *not long ago,* else they must surely have lost their heads back of the Second mountain; some piratical subsequent branch of a larger transverse stream, like the Passaic, would have beheaded them.

The only method now known by which these several doubly-transverse streams could have been established in the not too distant past is by superimposition from the Cretaceous cover that was laid upon the old Schooley peneplain. It has already been stated that when the Highlands and this region together had been nearly base-leveled the coastal portion of the resulting peneplain was submerged and buried by an unconformable cover of waste derived from the non-submerged portion; hence, when the whole area was lifted to something like its present height a new system of consequent streams was born on the revealed sea bottom. Since then time enough may have passed to allow the streams to sink their channels through the unconformable cover and strip it off, and thus superimpose themselves on the Triassic rocks below. We should therefore find them, in so far as they have not yet been re-adjusted, following inconsequent, discordant courses on the under formation. The existing overlap of the Cretaceous beds on the still buried Triassic portion of the old Schooley peneplain makes it evident that such an origin for the Watchung streams is possible, but it has not yet been independently proved that the Cretaceous cover ever reached so far inland as to cross the Watchung ridges.

Want of other explanation for the Watchung streams is not satisfactory evidence in favor of the explanation here suggested. There should be external evidence that the Triassic area has actually been submerged and buried after it was base-leveled to the Schooley peneplain and before it was uplifted to its present altitude; other streams as well as the ones thus far indicated should bear signs of superimposition, and if adjustment of the superimposed courses has begun it should be systematically carried farthest near the largest streams. I shall not here state more than in brief form the sufficient evidence that can be quoted in favor of the first and second requisites. Suffice it to say that the overlap of the Cretaceous beds (which contain practically no Triassic fragments) on the beveled Triassic strata at Amboy and elsewhere indicates submergence after base-leveling, and that the

pebbles, sands, and marls of the Cretaceous series point clearly to the Highlands as their source. The submergence must therefore have reached inland across the Triassic formation at least to the margin of the crystalline rocks. Some shore-line cutting must have been done at the margin of the Highlands during Cretaceous time, but the generally rolling surface of the old peneplain leads me to ascribe its origin chiefly to subaërial wasting. Moreover, the North branch of the Raritan, between Mendham and Peapack, and the Lockatong, a small branch of the Delaware on the West Hunterdon sandstone plateau, give striking indications of superimpositson in the discordance of their courses with the weaker structural lines of their basins, so unlike the thoroughly adjusted course of the Musconetcong and its fellows, the Pohatcong, the Lopatcong, and others."

The further proof of the inland extension of the Cretaceous and the resulting superimposed origin of the Watchung streams Prof. Davis states in detail by a series of deductive tests, which the writer will not introduce here, referring the reader to them for a fuller understanding of the subject.

The great economic value of the clays and sands of this formation, both on account of their fine quality and ready means of export, makes a detailed study of them and the bringing of the information of the 1878 report up to date, a matter of much import. Thus far the work performed by the writer has been chiefly that of determining the general geological features of the formation and mapping its boundaries.

CLAY MARL FORMATION.

The name Clay Marls was first applied by Prof. Cook to the deposits of this formation. Although the term does not adequately designate the same lithologically, it has been so definitely employed in a stratigraphical sense as to render its retention necessary.

The strata of the Clay Marl formation rest conformably upon those of the Raritan, and in the interbedded sands and clays near Cheesequake creek, gradually grade from the one into the other, so that the determination of a satisfactory dividing line between them is attended with very great difficulty.

The strata of the Clay Marl formation occupy the region to the east of the Raritan formation, and in Monmouth county attain a width of from five to seven miles. They are conformably overlain

by the deposits of the Lower Marl Bed which are situated upon their eastern border. In contradistinction to the lower boundary, it is generally easy to determine the upper limits of the Clay Marl formation, since a marked change in sedimentation characterized the succeeding period. The entire thickness of the formation is estimated at about 275 feet. The strike is N. 50° E., and the dip varies from 25 to 40 feet to the mile toward the southeast.

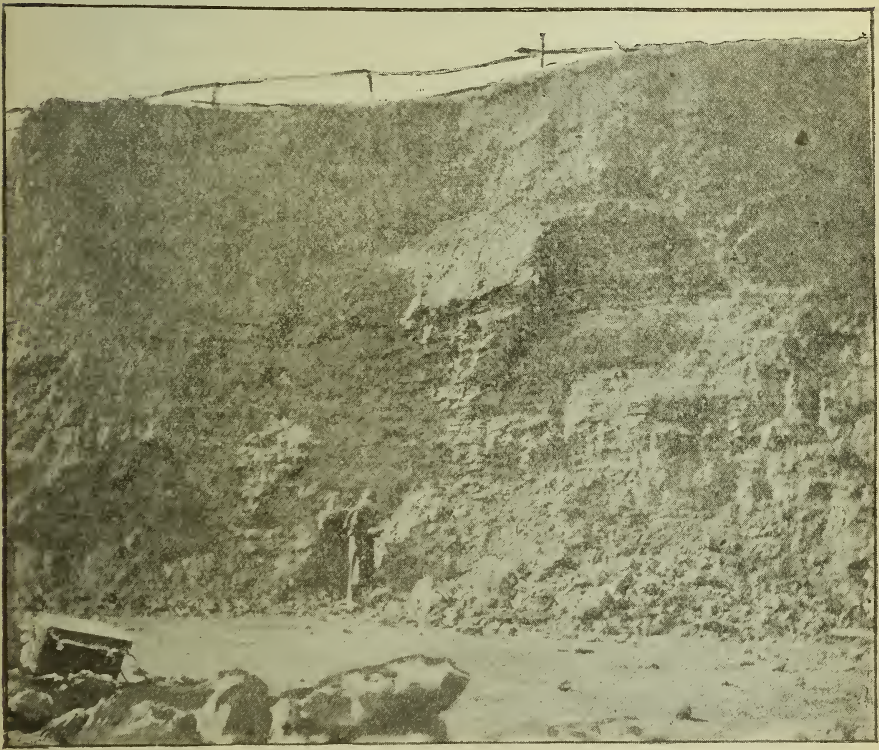


Fig. 2.
Section of Clay Marl formation on left bank of Matawan creek, near Keyport.

The deposits consist chiefly of dark-colored clays with interbedded layers of sand, the latter becoming very pronounced toward the upper portion of the formation. At infrequent intervals in the clay deposits are thin bands of green sand and green clay that only in a few localities become an important element in the series. The conditions neces-

sary for their formation only temporarily and locally prevailed. The character of the deposits shows that they were laid down at moderate depths, probably entirely within the shallow-water zone. During much of the period the accumulation of sediments was relatively slow as compared with the Raritan period, although very much more rapid than during the remainder of Cretaceous time. The deposits were derived from the crystalline rocks, with here and there a pronounced admixture of carbonate of lime derived from the shells of organisms. The presence of glauconite in the greensand layers is accounted for on the ground of secondary formation, and will be fully explained in a later chapter on the origin of greensand.

An excellent section is afforded by the bold bluffs on the shores of the Raritan bay between the mouth of Cheesequake creek and the Navesink Highlands. The clays are especially well shown between Cheesequake and Matawan creeks, both along the bay shore and also in the railroad cuts. At Matawan point and along the left bank of Matawan creek, in the large excavations that have been made for brick clay, are thin layers of greensand irregularly scattered through the deposits. At the base of the Highlands are interbedded sands and clays, the sands frequently laminated and often highly ferruginated from the hydrous iron oxide that has percolated through the deposits. Although reaching quite to the top of the bluff in the vicinity of Atlantic Highlands, the strata decline to the eastward until they disappear below water-level. The shore of the Raritan bay between the mouth of Matawan creek and Atlantic Highlands is low, and the Clay Marl formation throughout most of this region is buried beneath recent deposits. In the southern portion of the area mapped, along the line of the Freehold and Jamesburg railroad, is another good section of Clay Marl strata. This section is interesting in affording, about one mile east of Lower Jamesburg, in a railroad cut, a layer of greenish sandy clay several feet in thickness. Nearly on the southern edge of the map at Bergen Mills a boring of twenty feet was made into a deposit of green clay without passing through it. That the Clay Marl formation at times contains an important admixture of greensand and clay is shown further by the fact that the strata have been frequently dug for marl and at times with good results. Prof. Cook mentions twenty pits where the Clay Marl deposits have been dug as fertilizers. On the whole, however, the greensand holds a

much less important position in the Clay Marl formation than in the overlying members of the Cretaceous series.

In the intermediate area lying between the Freehold and Jamesburg railroad and the Raritan bay there are few extensive sections of Clay Marl strata. The clays and sands outcrop over much of the area and

Fig. 3.
Section of Clay Marl formation near Matawan.

determine the character of the soils, although frequently intermixed with later deposits. Along the eastern border of the Clay Marl formation in the vicinity of the higher lands of the Highland range more frequent sections are found than elsewhere throughout the region.

On the southeast side of the Highlands several streams in their upper courses cut down to the Clay Marl strata. The two large tributaries of Hop brook, which unite at a short distance below Holmdel, run nearly their entire length upon the Clay Marl formation. The lower banks of these streams throughout this distance and even a short distance beyond their junction, are formed of sands and interstratified clays and sands that are readily distinguished from the deposits of the Lower Marl Bed which overlie them and which further characterize the Clay Marl formation on the western and northern side of the Highlands. As the streams in general cut but a short distance into the Clay Marl strata, the width of exposure in each instance is limited, and on the map the surface outcrop appears as long, irregular bands that follow the windings of the stream channels. A third detached outcrop of Clay Marl strata is found at the headwaters of Big brook, another tributary of Hop brook. It occurs under similar conditions as upon the other tributaries. Since all of the streams are flowing in the direction of the dip of the strata, they cease to cut into the Clay Marl deposits when the pitch of the channel is reduced upon passing out into the lowlands south of the Highland range.

The fossils of the Clay Marl formation have not been as yet very fully collected or studied. Prof. Whitfield refers a number of species to that horizon, but, as he himself states, there is much doubt in the case of many of them. The specimens collected in the past from New Jersey generally had no locality names, so that they have no value from a stratigraphical standpoint. Some of the species are known to be identical with those from the Lower Marl Bed, while others have not been found there. Before any definite knowledge can be gained in regard to the fauna of the Clay Marl formation, systematic collection of the fossils must be undertaken.

Fossils have been found at Crosswicks, at Haddonfield, on the Pensauken creek near the crossing of the Philadelphia and Long Branch railroad, at Woodbury, and other points.

The clays of the Clay Marl formation, near the shores of the Raritan bay, particularly in the vicinity of Matawan, are extensively used in the making of brick.

LOWER MARL BED.

The Lower Marl Bed, so named by Prof. Cook, is perhaps better known than any other member of the coastal series of New Jersey, both on account of the many and valuable pits that have been opened for marl within its limits, and also on account of the great number of fossils that have been collected and described from it.

The strata of the Lower Marl Bed overlie the Clay Marl formation conformably, although distinguished from it by a marked change in the character of the deposits, so that the boundary line may be readily detected at all points. So sharp is the break that the auger has constantly been resorted to for its determination, where natural exposures were not found. Its upper limits, bordering the Red Sand formation, although not so sharply defined, are readily recognized in most instances.

The Lower Marl Bed is a characteristic greensand, glauconite entering to a marked extent into its composition. The lower two or three feet of the bed are frequently more highly quartzose than the overlying strata, in this respect showing the change from the sandy layers of the upper portion of the Clay Marl formation to the typical greensands of the Lower Marl Bed. It has been referred to under the name of sand marl. Above the sand marl is a very compact blue marl, which is highly glauconitic, and contains a considerable admixture of fine mineral particles and comminuted shells. Near the middle of the blue marl bed is a firm shelly layer, a foot or so in thickness, which is composed almost entirely of the shells of *Gryphœa vesicularis*. The upper portion of the bed again shows the presence of much land-derived material. It is highly argillaceous, and, just at the top, frequently quite sandy.

In general, there was a decided deepening of the waters during the period of the accumulation of the deposits of the Lower Marl Bed as compared with previous Cretaceous time. Deposition was also much less rapid, as is shown in the production of the extensive greensand deposits, the origin of which will be more fully explained in a later chapter. The deposits of the Lower Marl Bed were doubtless formed near the border of the shallow-water zone, at a distance of perhaps ten to fifteen miles off the coast, under conditions similar to those in existing seas where greensand accumulation is now going on.

The Lower Marl Bed varies from thirty to fifty feet in thickness. The strike changes locally, but is generally N. 50° E., which has been hitherto mentioned as characteristic of the earlier formations. As

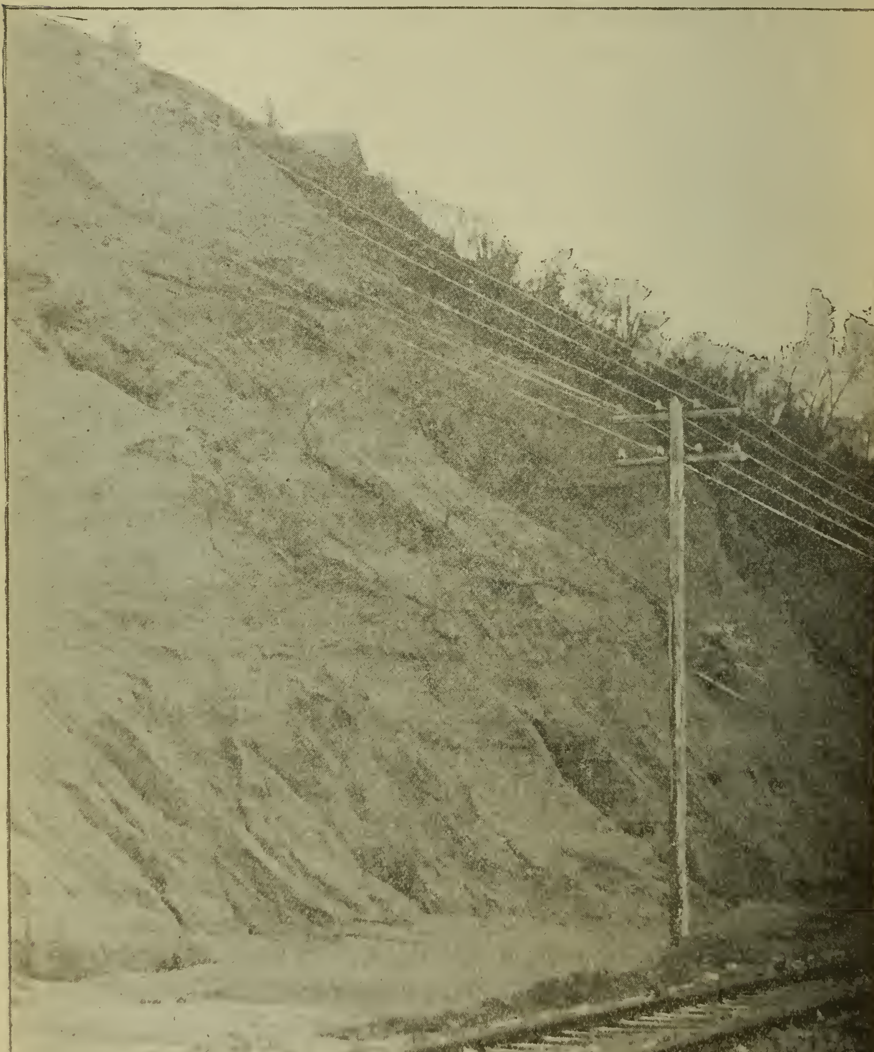


Fig. 4.
Section of bluff at Atlantic Highlands, showing Clay Marl formation, Lower Marl Bed, and Red Sand formation.

the boundary between the Clay Marl formation and the Lower Marl Bed is, as previously stated, one of the most clearly recognized in the coastal series, on account of the difference in the character of the deposits of the two horizons, the inequalities in the line of contact may be very easily observed. This is distinctly exhibited along the north and west planks of the Highland range, and may be clearly followed to and beyond the Freehold and Jamesburg railroad. A difference of thirty or forty feet in vertical elevation is recognized here.

The Lower Marl Bed is found chiefly outcropping on the north and west flanks of the Highland range, so that the areal distribution of the strata is not great. Upon the steeper slopes it becomes much contracted and is represented by a narrow band upon the map.

A typical section is shown upon the high bluffs of the Navesink Highlands. Overlying the Clay Marl deposits, just to the east of Atlantic Highlands, the Lower Marl Bed has a thickness of about forty feet. It is here composed of two or three feet of sandy marl at the base, which is overlain by twenty-five feet of greensand, becoming argillaceous in the upper part. Capping this, is a deposit of black clay fifteen feet in thickness, the upper portion of which is highly micaceous.

Constant sections are to be found in the marl pits all along the line of outcrop to the southwestward. It is seldom, however, that a complete series can be obtained, as the bottom of the bed is not often reached in these artificial exposures.

The larger streams which flow to the south and east from the Highland range, have cut very generally into the Lower Marl Bed, and along the broader and deeper channels have afforded wide surface exposures of that formation. Along some of the deeper lines of depression across the Highland range, the surface exposure extends continuously from the west and north sides to the east and south. This is shown along two of the larger streams entering the Navesink river from the north, and, upon even a larger scale, along Hop brook and its tributaries.

Along the thinned-out western edge of the formation, the greensand has been extensively weathered, so that it is often difficult to separate it from the overlying Red Sand. This is distinctly shown near Robertsville, where the bed stands at a high elevation and has been so much eroded that it forms but a thin coating over a consider-

able area. As the thicker and more compact portions still show the unaltered greensand, there can be no doubt as to its stratigraphic position.

The fossils of the Lower Marl Bed are very numerous, far exceeding in number of species, so far as the animal forms are concerned, those from all the other formations combined. The conditions must have been unusually favorable for the existence of this varied fauna, while the great number of individuals shows that those conditions must also have been very favorable for their interment and long preservation. They differ greatly, however, in their state of preservation. The representatives of the *Ostrœidœ* and *Spondylidœ* are found with their shells intact, while most of the other molluscan types are known only in the form of casts. The shells of the common species *Exogyra costata* and *Gryphœa vesicularis* are so hard that fine specimens are frequently picked up in the fields which have been strewn with marl. The localities from which the specimens hitherto collected and described were obtained are so indefinitely stated in most instances that it is impossible to tell to what horizon they properly belong. It even becomes very uncertain in many instances whether the specimens were derived from the Clay Marl formation or from the Lower Marl Bed. Until systematic collection is undertaken it is impracticable to try and separate them.

In his recent publications upon the palæontology of New Jersey Prof. R. T. Whitfield describes from the Lower Marl Bed 2 species of Brachiopoda, 155 species of Lamellibranchiata, 127 species of Gasteropoda, and 19 species of Cephalopoda. In addition to these four classes, remains of Foraminifera, Echimodermata, Bryozoa, Crustacea, and Vertebrata have also been obtained.

The following list is complete for the classes given:

ECHINODERMATA.

Catopygus pusillus Clark.

Cassidulus florealis Morton.

BRACHIOPODA.

Terebratula Harlani Morton.

" *Vanuxemi* Lyell and Forbes.

Terebratula plicata Say.

LAMELLIBRANCHIATA.

Ostrea denticulifera Conrad.
" *crenulimarginata* Gabb.
" *larva* Lamarck.
" *plumosa* Morton.
" *subspatula* Lyell and Forbes.
" *tecticosta* Gabb.
Gryphæa convexa Morton.
" *mutabilis* Morton.
" *vesicularis* Lamarck.
" *var. navia* Roemer.
Exogyra costata Say.
Anomia argentaria Morton.
" *tellinoides* Morton.
Diploschiza cretacea Conrad.
Paranomia lineata Conrad.
" *scabra* Morton.
Pecten planocostatus Whitfield.
" *quinquenarius* Conrad.
" *tenuitestus* Gabb.
" *venustus* Morton.
" (*Chlamys*) *craticulus* Morton.
" (*Syncyclonema*) *perlamellosus* Whitfield.
Amusium simplicum Conrad.
" *Conradi* Whitfield.
Camptonectes (*Amusium*) *burlingtonensis* Gabb.
" *parvus* Whitfield.
Neithea quinquecostata Sowerby.
Spondylus gregalis Morton.
Dianchora echinata Morton.
Plicatula urticosa Morton.
Radula acutilineata Conrad.
" *pelagica* Morton.
" *recticulata* Lyell and Forbes.
Mytilus oblivius Whitfield.
Modiola burlingtonensis Whitfield.
" *Julia* Lea.
Lithodomus affinis Gabb.
" *ripleyana* Gabb.
Pteria laripes Morton.
" *navicula* Whitfield.
" *petrosa* Conrad.
Meleagrinella abrupta Conrad.
Gervilliopsis ensiformis Conrad.
" *minima* Whitfield.
Inoceramus Barabini Morton.
" *perovalis* Conrad.
" *pro-obliqua* Whitfield.
" *quadrans* Whitfield.
" *Sagensis* Owen.
" *Sagensis, var. quadrans* Whitfield.
Pinna laqueata Conrad.
Arca altirostris Gabb.
Nemoarca cretacea Conrad.
Nemodon angulatum Gabb.
" *brevifrons* Conrad.
" *Eufaulensis* Gabb.
Breviarca Saffordi Gabb.
Trigonarca cuneiformis Conrad.
" *transversa* Gabb.
Cibota multiradiata Gabb.
" *obesa* Whitfield.
" *rostellata* Morton.
" *uniopsis* Conrad.
Idonearca antrosa Morton.
" *tippana* Conrad.
" *vulgaris* Morton.
Axinea alta Whitfield.
" *Mortoni* Conrad.
Nucula monmouthensis Whitfield.
" *percrassa* Conrad.
" *perequalis* Conrad.
" *Slackiana* Gabb.
Nuculana compressifrons Conrad.
" *Gabbana* Whitfield.
" *longifrons* Conrad.
" *pinniformis* Gabb.
" *protexta* Gabb.
Perissonota protexta Conrad.
Nucularia papyria Conrad.
Trigonia cerulea Whitfield.
" *eufaulensis* Gabb.
" *Mortoni* Whitfield.
Crassatella cuneata Gabb.
" *monmouthensis* Gabb.
" *prora* Conrad.

Crassatella sublana Conrad.
" *tranversa* Gabb.
" *vadosa* Morton.
Scambula perplana Conrad.
Gouldia Conradi Whitfield.
" *decemnaria* Conrad.
" *declivis* Conrad.
" *paralis* Conrad.
Vetocardia crenulirata Lea.
" *octolirata* Gabb.
Lucina cretacea Conrad.
" *Smockana* Whitfield.
Diceras dactyloides Whitfield.
Cardium eufaulensis Conrad.
" *ripleyanum* Conrad.
" *ripleyense* Conrad.
" (*Criocardium*) *dumosum* Conrad.
" (*Criocardium*) *multiradiatum* Gabb.
Pachycardium burlingtonense Whitfield.
Protocardium perelongatum Whitfield.
Fulvia tenuis Whitfield.
Fragum tenuistriatum Whitfield.
Leiopistha elegantula Roemer.
" *inflata* Whitfield.
" *protexta* Conrad.
Cymella Meeki Whitfield.
Veniella Conradi Morton.
" *decisa* Morton.
" *elevata* Conrad.
" *inflata* Conrad.
" *subovalis* Conrad.
" *trapezoidea* Conrad.
" *trigona* Gabb.
Sphæriola umbonata Whitfield.
Callista delawarensis Gabb.
Aphrodina tippana Conrad.
Cyprimeria excavata Morton.
" *densata* Conrad.
" *depressa* Conrad.
" *Heilprini* Whitfield.
" *spissa* Conrad.
Dosinia erecta Whitfield.
" *Gabbi* Whitfield.
Tenea pinguis Conrad.
Tellimera eborea Conrad.
Linearia contracta Whitfield.
" *metastriata* Conrad.
Aeora cretacea Conrad.
Aenona eufaulensis Conrad.
" *papyria* Conrad.
Corimya tenuis Whitfield.
Donax Fordi Lea.
Veleda lintea Conrad.
" *tellinoides* Whitfield.
" *transversa* Whitfield.
Pholadomya occidentalis Morton.
" *Roemeri* Whitfield.
Periplomya elliptica Conrad.
Cercomya peculiaris Conrad.
Corbula crassiplica Gabb.
" *Foulki* Lea.
" *subcompressa* Gabb.
Panopæa decisa Conrad.
Solyma lineolata Conrad.
Leptosolen biplicata Conrad.
Legumen appressum Conrad.
" *planulatum* Conrad.
Siliqua cretacea Gabb.
Pholas cithara Morton.
" *lata* Whitfield.
Martesia (*Pholas*) *cretacea* Gabb.
Teredo irregularis Gabb.
Clavagella armata Morton.

GASTEROPODA.

Tudicla planimarginata Whitfield.
Pyropsis corrina Whitfield.
" *elevata* Gabb.
" *naticoides* Whitfield.
" *obesa* Whitfield.
" *octolirata* Conrad.
Pyropsis perlata Conrad.
" *Reileyi* Whitfield.
" *retifer* Gabb.
" *Richardsoni* Tuomey.
" *septemlirata* Gabb.
" *trochiformis* Tuomey.

Perissolax dubia Gabb.
Pyrifusus erraticus Whitfield.
" *cuneus* Whitfield.
" *Macfarlandi* Whitfield.
" *Meeki* Whitfield.
" *mullicænsis* Gabb.
" *pyruloides* Gabb.
" *turritus* Whitfield.
Neptunella mullicænsis Whitfield.
Triton (*Epidromus*) *præcedens* Whitfield.
Trachytriton atlanticum Whitfield.
" *holmdelense* Whitfield.
" *multivaricosum* Whitfield.
Fusus holmdelensis Whitfield.
Serrifusus? *crosswickensis* Whitfield.
" (*Lirofusus*) *nodocarinatus* Whitfield.
Odontofusus Slacki Gabb.
" *medians* Whitfield.
" *rostellaroides* Whitfield.
" *typicalis* Whitfield.
Volutomorpha Conradi Gabb.
" *Gabbi* Whitfield.
" *ponderosa* Whitfield.
" (*Piestochilus*) *bella* Gabb.
" *Kanei* Gabb.
" *mucronata* Gabb.
Eripachya ? paludinaformis Whitfield.
Euthria ? fragilis Whitfield.
Tritonidea obesa Whitfield.
Turbinella ? parva Gabb.
" *subconica* Gabb.
" *verticalis* Whitfield.
Vasum conoides Whitfield.
Voluta ? delawarensis Gabb.
Volutoderma biplicata Gabb.
" *ovata* Whitfield.
Rostellites angulatus Whitfield.
" *nasutus* Gabb.
" *texturatus* Whitfield.
Turricula leda Whitfield.
" *Reileyi* Whitfield.
" *scalariformis* Whitfield.
Cancellaria (*Merica*) *subalta* Conrad.
Morea naticella Gabb.
Turbinopsis angulata Whitfield.
" *curta* Whitfield.
" *elevata* Whitfield.
" *Hilgardi* Conrad.
" *major* Whitfield.
" *plicata* Whitfield.
Surcula strigosa Gabb.
Cithara crosswickensis Whitfield.
" *mullicænsis* Whitfield.
Rostellaria curta Whitfield.
" *fusiformis* Whitfield.
" *Hebe* Whitfield.
" *spirata* Whitfield.
Alaria rostrata Gabb.
Anchura abrupta Morton.
" *var. acutispira* Whitfield.
" *arenaria* Morton.
" *pagodaformis* Whitfield.
" *pannata* Morton.
" *solitaria* Whitfield.
" (*Drepanocheilus*) *compressa* Whitfield.
Cypræa (*Aricia*) *Mortoni* Gabb.
Dolium (*Doliopsis ?*) *multiliratum* Whitfield.
Ficus præcedens Whitfield.
Natica abyssina Morton.
Lunatia Halli Gabb.
Gyrodes Abbottii Gabb.
" *altispira* Gabb.
" *crenata* Conrad.
" *infracarinata* Gabb.
" *obtusivolva* Gabb.
" *petrosus* Morton.
Amauropsis Meekana Whitfield.
" *punctata* Gabb.
Margarita abyssina Gabb.
Margaritella Abbottii Gabb.
Xenophora leprosa Morton.
Endoptigma umbilicata Tuomey.
Scalaria Hercules Whitfield.
" *? pauperata* Whitfield.
" *Sillimani* Morton.
" (*Opalia*) *Thomasi* Gabb.
Turritella compacta Whitfield.

Turritella encrinoides Morton.
" *? granulicosta* Gabb.
" *Hardimanensis* Gabb.
" *Lippincotti* Whitfield.
" *vertebroides* Morton.
Laxispira lumbricalis Gabb.
Siliquaria pauperata Whitfield.
Diploconcha ? cretacea Conrad.
Obeliscus conellus Whitfield.
Modulus lapidosa Whitfield.
Margarita abyssina Gabb.
Margaritella Abbotti Gabb.
Helcion ? tentorum Morton.
Actæon cretacea Gabb.
" *Forbesiana* Whitfield.
Actæon Gabbana Whitfield.
" *subovoides* Whitfield.
Globiconcha curta Gabb.
Cinulia (*Oligoptycha*) *naticoides* Gray.
" " *ovoidea* Gabb.
Avellana bullata Morton.
Cylichna recta Gabb.
Bulla Mortoni Lyell and Forbes.
Dentalium Ripleyanum Gabb.
" *subarcuatum* Conrad.
Falcula falcatum Conrad.
Diploconcha ? (*Serpula ?*) *cretacea* Conrad.

CEPHALOPODA.

Nautilus Dekayi Morton.
Ammonites complexus Meek.
" *delawarensis* Morton.
" *dentato-carinatus* Roemer.
" *Vanuxemi* Morton.
" (*Placenticeras*) *placenta* De Kay.
" (*Placenticeras*) *tilifer* Morton.
Scaphites hippocrepis De Kay.
" *iris* Conrad.
Scaphites nodosus Owen.
" *reniformis* Morton.
" *similis* Whitfield.
Turrilites pauper Whitfield.
Heteroceras Conradi Morton.
Ptychoceras (*Solenoceras*) *annulifer* Morton.
Baculites asper Morton.
" *compressus* Morton.
" *ovatus* Morton.
Belemnitella americana Morton.

The Lower Marl Bed has been a source of great economic wealth to the State, since the greensands have long been dug as fertilizers. Their use began in the last century, the marl being first employed as a fertilizer near Marlboro in 1768, although it did not become general until about 1820. The greensand marl is not as extensively employed as formerly, on account of cheaper fertilizers; still the great fertility of much of the land of this portion of the State is to be traced directly to its use. Particularly rich are those lands found along the surface outcrop of the formation; here the soils are oftentimes almost exclusively composed of greensand.

Many analyses of the marl have been made, and although they show some variations in the percentage of the different substances

present, the following analysis is given as typical for the formation. The phosphoric acid, upon the presence of which depends to a large degree the value of the marl as a fertilizer, varies from a mere trace to somewhat more than two per cent. The proportion of carbonate of lime also varies greatly, depending upon the fossiliferous character of the deposit:

ANALYSIS OF MARL FROM MARLBORO, MONMOUTH COUNTY.

Phosphoric acid	1.14
Sulphuric acid	0.31
Silicic acid and sand	38.70
Potash	4.47
Magnesia	1.21
Oxide of iron and alumina	30.67
Carbonate of lime	13.91
Water	11.22
	99.63

Mechanical analyses which have been made of the marl show varying proportions of glauconite grains. In a sample from Marlboro the marl was found to be composed of 58.4 per cent of glauconite grains, 40.2 per cent. of foreign mineral particles, 0.7 per cent. of iron crusts, and 0.7 per cent. of shell fragments. Another sample, from Manalapan, showed 75 per cent. of glauconite grains, and 25 per cent. of foreign mineral particles.

RED SAND FORMATION.

The strata overlying the Lower Marl Bed, on account of their widespread red color, were called the Red Sand by Prof. Cook. This formation is conformable to the Lower Marl Bed, and consists of sands and clays of various colors with red predominating. The red sand, although not a pure greensand like much of the preceding formation, has grains of glauconite widely scattered through the deposit. This glauconitic material, however, has been generally oxidized, so that its original green color has been lost. Upon examination it is evident that the pronounced red color of the formation is largely to be accounted for by the oxidation of these greensand grains.

The more highly quartzose character of the Red Sand formation, as compared with the Lower Marl Bed, points to a greater influx of land-derived materials. As the greensand deposits are not formed

necessarily at great depths, a change in the current or in the drainage of the land might increase or diminish the amount of deposition without a corresponding change in the depth of the waters.

The Red Sand formation maintains a thickness of about 100 feet across the area represented upon the map. The lower ten or fifteen feet are often composed of a black sand or sandy clay, although this may be at times red in color as the iron becomes oxidized. The central portion of the formation is highly quartzose, very loose in texture, and with grains of glauconite, in a partially or entirely altered state, scattered through it in variable amounts. At the top of the formation is an indurated clayey layer that generally has a distinctly greenish color, although at times changed to red. This hardened stratum has

Fig. 5.

Deep cut south of Keyport, showing indurated layer of Red Sand formation overlaid by Middle Marl Bed.

had an important influence in the development of the topography of the region, and the high ridge of the Highland range is to a considerable extent due to its presence. Many of the isolated hills to the south and east of the range are capped by the consolidated layers of this deposit.

The Red Sand formation forms much of the Highland range and the region to the south of the same, extending to and beyond Swimming river and forming most of Rumson Neck. Its surface exposure is very great in eastern Monmouth county but gradually narrows towards the southwest. In the region about Barrentown the Red Sand is highly quartzose and unconsolidated, a character exhibited widely on the north bank of Swimming river.

The fossils of the Red Sand formation are in the main the same as in the Lower Marl Bed. The conditions were not as favorable for their preservation, however, as in the latter formation, so that there is a much smaller number of both species and individuals represented, while those that are found are in a very imperfect state. The larger and more solid forms, such as *Exogyra costata* and *Gryphœa vesicularis*, are most frequently encountered. No extensive collections, however, have as yet been made from the Red Sand, so that its fauna is not well known. Many have already been collected by the writer from the hardened clayey layers at the top of the formation, and a further study of these and additional forms will doubtless add to our knowledge of the life of the Red Sand period.

The deposits of the Red Sand formation are not used extensively for economic purposes, although the greenish hardened layers of the upper portions of the bed have been occasionally employed as fertilizers in eastern Monmouth county. Farther to the southwest, beyond the limits of the map, the Red Sand is more highly glauconitic and has been more generally dug for marl.

MIDDLE MARL BED.

The Middle Marl Bed, the second of the three marked greensand horizons recognized by Prof. Cook, is found directly overlying the Red Sand formation. It is chiefly exposed to the southeast of the latter, where it covers a tract of country several miles in width. Within the Red Sand belt it is frequently found as isolated patches, capping the highest points and stretching to the Highland range.

The Middle Marl Bed is largely a greensand throughout, although much more highly glauconitic in the lower than the upper half of the formation. The lower half, which we may refer to as the distinctly greensand member, is generally argillaceous in its lower portions, and, towards the southwest, chocolate colored. The latter is frequently referred to as Chocolate Marl. In its upper portions it becomes calca-

Fig. 6.

Distant view of the deep cut south of Keyport, with Middle Marl Bed capping the summit of the range of hills.

reous from the great number of fossil shells found imbedded in the strata. The upper half of the Middle Marl Bed contains much less glauconite and is highly calcareous, frequently containing as much as 80 per cent. of carbonate of lime. It is known as the Yellow Limestone. In Monmouth county the yellow limestone is softer and

more glauconitic than in the region to the southwest, so that its separation from the lower horizon is not always readily made. In the central district, hardened layers of limestone occur, which have been in some localities burned for lime, or used directly for building purposes.

The thickness of the Middle Marl Bed has been estimated at forty-five feet, and is about equally divided between the greensand and limestone horizons.

The Middle Marl Bed rests upon the Red Sand formation with a sharp line of contact, which may be readily determined except along the thinned-out western edge of the formation, where extensive oxidation makes their separation often difficult. Upon examination of the materials, a much smaller proportion of weathered or partially weathered grains of glauconite is found in the Middle Marl Bed than in the Red Sand formation.

The most extensive development of the Middle Marl Bed within the area of the map is to be found to the south of Yellow brook. In the region just south of Colt's Neck several pits have been opened in the greensand horizon. Numerous detached areas of the greensand division are found to the north of the main outcrop of the formation. In general, these patches of greensand are small in extent and of little thickness. They are found at several points on Rumson Neck and to the north of Yellow brook at Phalanx and Barrentown. Still further to the north they cap the range of the Highlands at numerous points throughout most of its length. The greensand is in all cases more or less oxidized, but may be readily recognized.

The fossils of the Middle Marl Bed are very numerous at certain horizons, but much fewer species have been recognized than in the Lower Marl Bed. The greensand member is not highly fossiliferous except in the upper six feet, although casts of shells and bones of vertebrates are not uncommon throughout the lower portion of the horizon. The upper six feet, however, are often packed with fossils, the lower four feet consisting almost exclusively of *Gryphæa vesicularis*, the upper two feet of *Terebratula Harlani*. These fossiliferous layers are remarkably persistent, and are found at many points across the State.

The yellow limestone member is characterized by the presence of Bryozoa, Echinodermata, Foraminifera, and Mollusca, the latter, however, holding an unimportant position as compared with the other

groups. The following list of fossils described from the Middle Marl Bed is complete for the classes given:

ECHINODERMATA.

Pentacrinus Bryani Gabb.
Goniaster mammillata Gabb.
Cidaris splendens Morton.
" *Walcotti* Clark.
Salenia tumidula Clark.
" *bellula* Clark.
Pseudodiadema diatretum Morton.
Coptosoma speciosum Clark.
Psammechinus cingulatus Clark.
Trematopygus crucifer Morton.
Catopygus oviformis Conrad.
Ananchytes ovalis Clark.
Cardiaster cinctus Morton.
Hemiaster parastatus Morton.
" *stella* Morton.
" *ungula* Morton.
Linthia tumidula Clark.

BRACHIOPODA.

Terebratula Harlani Morton.

LAMELLIBRANCHIATA.

Gryphæa Bryani, var. precedens Whitfield.
" *vesicularis* Lamarck.
" *var. navia* Roemer.
Gryphæostrea vomer Morton.
Modiola (Lithodomus) inflata Whitfield.
Modiola ovata Gabb.
Pinna rostriformis Morton.
Idonearca compressirostra Whitfield.
" *medians* Whitfield.
Isocardia Conradi Gabb.
Teredo tibialis Morton.
Gastrochæna Americana Gabb.

GASTEROPODA.

Pyropsis trivolvis Gabb.
Volutoderma Abbotti Gabb.
Natica abyssina Morton.
Lunatia Halli Gabb.
Cavoscala annulata Morton.
Pleurotomaria tritonensis Whitfield.
Pleurotrema solariformis Whitfield.

CEPHALOPODA.

Nautilus Bryani Gabb.
" *Dekayi* Morton.
Hercoglossa paucifex Cope.
Ammonites (Sphenodiscus) lenticularis Owen.
Baculites ovatus Morton.

The Middle Marl Bed has been widely used as a fertilizer, some of the richest pits in the State being opened in its strata. The following analysis of marl from Blue Ball, Monmouth county, a few miles to the south of Freehold, is typical of it:

Phosphoric acid	1.04
Sulphuric acid	1.44
Silicic acid and sand	54.11
Potash	6.98
Lime	0.48
Magnesia	3.79
Oxide of iron and alumina	23.39
Water	8.11
	99.34

Mechanical analyses which have been made of the marl show a large percentage of glauconite grains. A sample from Tinton Falls gave 82 per cent. of glauconite grains and 18 per cent. of foreign mineral particles. Another sample, from Blue Ball, gave 84.2 per cent. of glauconite grains and 15.8 per cent. of foreign mineral particles.

The hardened limestone layers, as previously mentioned, are burned for lime at certain points, as well as employed for rough building purposes.

UPPER MARL BED.

Under this division I have included not only the deposits so named by Prof. Cook, but likewise the Yellow Sand of that author, since upon stratigraphic grounds there is no good reason for its separation from the overlying strata. The Yellow Sand, wherever examined, is a distinct greensand, although less highly glauconitic than the greensand layers that overlie it. It has no distinctive fossils; in fact, none have hitherto been reported from it.

The Ash Marl of Prof. Cook, considered as the middle member of the Upper Marl Bed, is simply a highly-argillaceous greensand, and has been observed by the writer underlying as well as overlying the Greensand bed. The upper portion of the Upper Marl Bed, which was called Blue Marl by Prof. Cook, has been considered to be of Eocene age, although conformable to the underlying strata of the Upper Marl Bed. It seems desirable on account of the marked difference in its fauna, to separate this portion of the Upper Marl Bed from the underlying strata, and accordingly the following division is made into Manasquan Marl and Shark river Marl:

Manasquan Marl.

Under the name of Manasquan Marl is included the yellow sand, together with the greensand and ash marl of the Upper Marl Bed of Prof. Cook. The name is taken from the Manasquan river, where

an excellent section of the strata is found. The yellow sand, as stated above, contains no distinctive features of sufficient importance to warrant its separation from the Upper Marl Bed. It has been so regarded both in the preparation of the text and map.

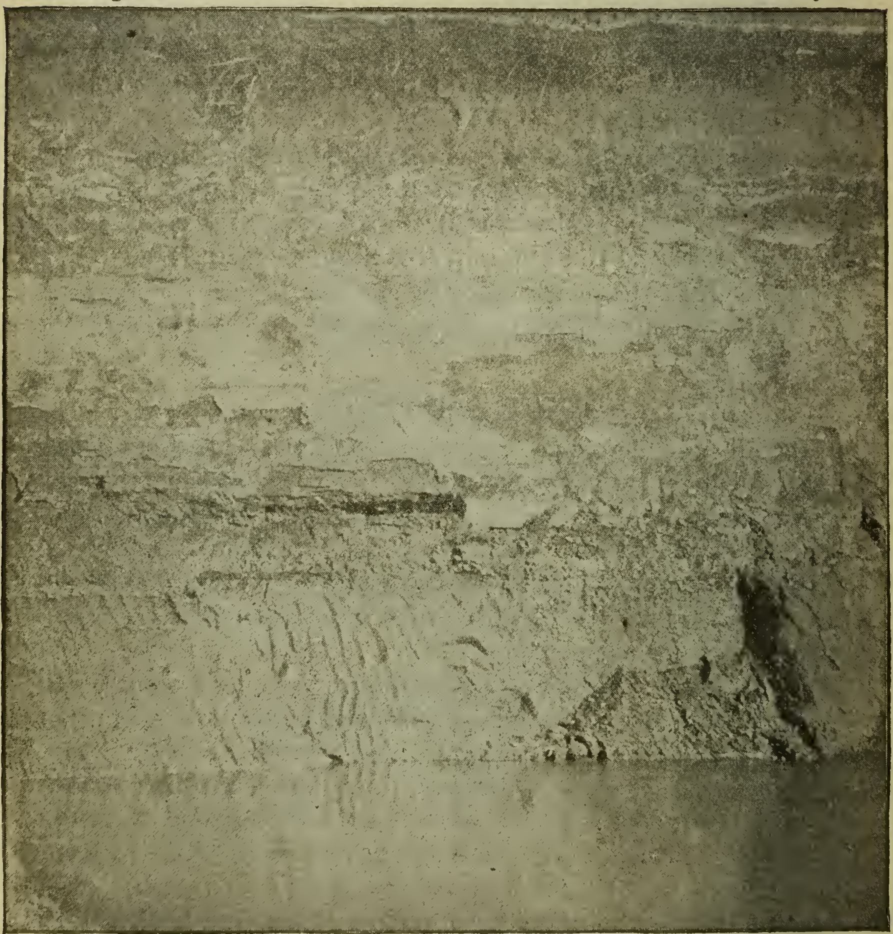


Fig. 7.

Section of Farmingdale marl pits, showing Upper Marl Bed overlaid by Miocene.

The Manasquan Marl is found to the southeast of the Middle Marl Bed, upon which it rests conformably. It is a greensand, highly quartzose in the lower part, and at times argillaceous in the upper

layers. The lower quartzose member is about forty feet in thickness, and the upper more glauconitic member about twenty-five feet, so that the entire thickness of the Manasquan Marl is approximately sixty-five feet. At the base of the upper member there is frequently a layer of fine clay, which has been described under the name of "fuller's earth."

The Manasquan Marl covers only a small area in the southwestern portion of the region represented upon the map. The greater portion of the tract is buried beneath later deposits, so that it outcrops at only a few points.

To the south of the area represented upon the map, at Shark river and Farmingdale, the best outcrops of this horizon are found, and especially at Farmingdale extensive pits have been opened. Views of the same are shown in Figures 7 and 8.

The fossils are confined exclusively to the greensand members, as none are known from the sandy strata of the lower horizon. The following list is complete for the classes given:

BRACHIOPODA.

Terebratulina atlantica Morton.

LAMELLIBRANCHIATA.

Ostrea glandiformis Whitfield.
Gryphæa Bryani Gabb.
Modiola Johnsoni Whitfield.
Arca quindecimradiata Gabb.
Cardita intermedians Whitfield.
Crassatella curta Conrad.
" *delawarensis* Gabb.
" *littoralis* Conrad.
" *rhombea* Whitfield.
Cardium (*Criocardium*) *nucleolus* Whitfield.
Veniella rhomboidea Conrad.
Caryatis? veta Whitfield.
Petricola nova-ægyptica Whitfield.
Veleda nasuta Whitfield.
Periplomya truncata Whitfield.
Panopæa elliptica Whitfield.

GASTEROPODA.

Caricella plicata Whitfield.
Volutoderma intermedia Whitfield.
Rostellites biconicus Whitfield.
Pleurotoma farmingdalensis Whitfield.
Rostellaria nobilis Whitfield.
Turritella pumila Gabb.
Pleurotomaria Brittoni Whitfield.
Bulla conica Whitfield.

The Manasquan marl has been extensively dug as a fertilizer, and on account of the high percentage of soluble phosphates contained in

it has been considered of exceptional value. The following analysis is that of a typical marl from Farmingdale:

Phosphoric acid	3.87
Sulphuric acid	0.31
Silicic acid and sand	54.75
Potash	4.11
Lime	5.46
Magnesia	2.99
Oxide of iron and alumina	21.66
Water	6.85
	100.00

Shark River Marl.

Under the name of Shark River Marl is included the so-called "Blue Marl" of Prof. Cook, which is found at the top of the Upper Marl Bed, and typically developed in the valley of Shark river. It is conformable to the underlying Manasquan marl wherever examined, while the highly glauconitic character of the deposits shows the similarity of the conditions that prevailed throughout the accumulations of the strata of the Upper Marl Bed.

The Shark River Marl is a marked greensand, with a slight admixture of argillaceous materials, while a hardened stony layer is commonly found directly at the top. The entire thickness of the Shark river marl is estimated at about twelve feet in the area of its typical development. It occurs at a few points in the extreme southeastern corner of the area represented upon the map, but it is largely buried beneath Pleistocene deposits.

The Shark river marl has the very greatest interest, since its fossils are considered to be of Eocene age, although its strata are conformable and very intimately connected lithologically with the underlying Cretaceous deposits.

Conrad, first in 1848 * and again more fully in 1865,† maintained the Eocene age of the Shark river marl, while Prof. Cook,‡ in 1883, stated that the deposits were unconformable with the underlying strata. More recently Whitfield has claimed the identity of several of the species with Eocene forms from the South Atlantic and Gulf States, but since all the specimens are casts, some of them poorly preserved, there

* Phila. Acad. Nat. Sci. Jour., new ser., Vol. 1, 1848, p. 129.

† Phila. Acad. Nat. Sci. Proc., Vol. 17, 1865, pp. 71, 72.

‡ Geol. Surv. New Jersey, Ann. Rep., 1883, pp. 13–19.

is some doubt upon the subject. So far as the generic relations of the molluscan types are concerned, some have a more Eocene than Cretaceous aspect, yet many could as well be referred to the one as the other. There are, it is true, on the other hand, no distinctly Cretaceous types, while the genus *Aturia* is not known earlier than the Eocene. It is, however, impossible to correlate the Shark river marl with any other known Eocene strata, and the writer, in his Correlation Essay upon the Eocene of the United States, treated it as an independent province. It is readily conceivable that deposition did go on, in moderately-deep waters, such as prevailed at the time, uninterruptedly from the Cretaceous to the Eocene, although elsewhere upon the Atlantic coast, under shallower water conditions, a marked break and change in the character of the deposits occurred.

The invertebrate fossils described from the Shark River Marl are:

LAMELLIBRANCHIATA.

Ostrea glauconoides Whitfield.
" *(Alectrionia) linguafelis* Whitfield.
" *panda* Morton.
Gryphæa vesicularis Lamarck.
Pecten Kneiskerni Conrad.
" *Rigbyi* Whitfield.
Avicula annosa Conrad.
Nucula circe Whitfield.
Nuculana albaria Conrad.
Nucularia secunda Whitfield.
Axinea Conradi Whitfield.
Astarte castanella Whitfield.
Astarte planimarginata Whitfield.
Cardita perantiqua Conrad.
" *Brittoni* Whitfield.
Crassatella alta Conrad.
" *obliquata* Whitfield.
Protocardium curtum Conrad.
Caryatis ovalis Whitfield.
Veleda equilatera Whitfield.
Corbula (Neæra) nasutoides Whitfield.
Neæra æquivalvis Whitfield.
Parapholas Kneiskerni Whitfield.
Teredo emacerata Whitfield.

GASTEROPODA.

Murex (Pleuronotus ?) levavaricosa Whitfield.
Rhinocantha ? Conradi Whitfield.
Triton eocenense Whitfield.
Pseudoliva vetusta ? Conrad.
Fusus angularis Whitfield.
" *paucicostatus* Whitfield.
" *perobesus* Whitfield.
" *pluricostatus* Whitfield.
Fusus (Neptunea ?) eocenicus Whitfield.
" *(Neptunea) hector* Whitfield.
" " *var. multilineatus* Whitfield.
" *(Neptunea) staminea* Conrad.
" *(Urosalpinx) multicostatus* Whitfield.
Clavella raphanoides Conrad.

Fasciolaria hercules Whitfield.
" *propinqua* Whitfield.
" *Samsoni* Whitfield.
Caricella ponderosa Whitfield.
" *pyruloides* Conrad.
Voluta lelia Whitfield.
" *parvula* Whitfield.
" *perelevata* Whitfield.
" *scaphoides* Whitfield.
" (*Scaphella*) *Newcombiana* Whitfield.
" (*Amoria*) *vesta* Whitfield.
Volutilithes cancellata Whitfield.
" *Sayana* Conrad.
Cancellaria rudis Whitfield.
Pleurotoma surculitiformis Whitfield.
" *regularicostata* Whitfield.
" (*Surcula*) *altispira* Whitfield.
Surcula perobesa Whitfield.
Surculites avenosus Conrad.
" *cadaverosus* Whitfield.
" *curtus* Whitfield.
Conus subsauridens Whitfield.
Calyptraphorus velatus Conrad.
Cypræa sabuloviridis Whitfield.
Cassidaria carinata Lamarck.
Ficus penitus Conrad.
Natica globulella Whitfield.
Xenophora lapiferens Whitfield.
Architectonica annosa Conrad.
Scalaria tenuilirata Whitfield.
Mesalia elongata Whitfield.
Leptomaria gigantea Whitfield.
" *pergranulosa* Whitfield.
" *perlata* Conrad.
Trematofusus venustus Whitfield.
Actæon prisca Conrad.
Tornatellæa lata Conrad.
Tornatina Wetherelli Lea.

CEPHALOPODA.

Nautilus Cookana Whitfield.
Aturia Vanuxemi Conrad.

A considerable number of vertebrate fossils have likewise been reported from the Shark River Marl, but in regard to many of them there is reason to believe that they were either collected from the overlying Miocene or underlying Cretaceous. There is accordingly much uncertainty as to the vertebrate evidence. One genus, *Anchippodus*, if correctly reported, is not known from other than Eocene deposits.

MIOCENE.

To the southeast of the greensand belt, and overlying the Upper Marl Bed unconformably, are deposits of sand and clay that belong to the Miocene. A delimitation of their areal distribution has been little attempted in the past, and, in fact, there are many obstacles to progress in this regard, on account of the almost complete absence of fossils, and the thick coating of Pleistocene materials which covers much of the area. The Miocene deposits are to a large extent composed of coarse sediments, which are ill-adapted for the preservation of fossils. They were largely formed in shallow waters,

where deposition was rapid and mechanical disturbances active. In this respect they differ in a marked degree from deposits of like age farther to the south in Maryland and Virginia. Chiefly from a study of the deposits in the southern part of the State, Prof. W. H. Dall compares the character of the sedimentation to that occurring off Cape Hatteras at the present time, and further states that the genera obtained from the latter locality are in the main identical with those from the New Jersey strata.

Few localities have, up to the present time, been found where fossils of undoubted Miocene age have been discovered. Many and well-preserved specimens have long been collected from the vicinity of Shiloh and Jericho, in southern New Jersey, but little attempt has been made to correlate the deposits of that area with the more southern representatives of the Miocene.

Prof. Cook, in his Geology of New Jersey (1868), refers to the Miocene, a dark micaceous clay, recognized at several points along the eastern border of the greensand belt. The extent of the strata and the deposits which characterize them are, however, very indefinitely stated.

The opening of a well to the depth of 1,150 feet at Atlantic City, in 1886–87, showed the existence of several hundred feet of Miocene strata, and at the same time indicated the wide distribution of the deposits of that age throughout the eastern portion of the State.

A section of the well-boring was prepared by Mr. Lewis Woolman,* and is presented below. The portion below 400 feet is referred by him to the Miocene:

SECTION OF WELL AT ATLANTIC CITY.

Superficial sands, gravels and clays; wood found at the base	285 feet.	
Black clays and sands	131 "	416 feet.
Bluish clay	19 "	435 "
Greenish clays and marls with much comminuted shell; some shark teeth, and many seams of brittle, marly clay of gray color	235 "	670 "
Blackish and brownish sands	21 "	691 "
Chocolate clay	31 "	722 "
Fossiliferous clays and sands; shells and sharks' teeth	84 "	806 "

* Philadelphia Acad. Nat. Sci. Proc., 1887, pp. 339, 340.

Non-fossiliferous sands, alternating blackish, whitish, and reddish-brown in color	60 feet.	866 feet.
Dark marls and clays	73 "	939 "
Green marls (various shades) and black marls	60 "	999 "
Sands mostly yellowish-green and full of barnacles	120 "	1,119 "
White sands; water	2 "	1,121 "

The fossils obtained from the well-boring were examined by Prof. Angelo Heilprin,* who recognized over fifty species, many of them characteristic of the Miocene deposits farther south. The depths of only three are recorded, viz., *Turritella plebia* from 450 feet, *Corbula elevata* from 730 feet, and *Perna maxillata* from 800 feet.

A second well-boring was made in 1888. In a series of clay beds, extending from 387 to 638 feet, numerous diatoms and foraminifera are reported by Mr. Woolman. About one hundred species of diatoms alone are mentioned, most of them hitherto recognized in the Maryland and Virginia deposits. At depths of 435 and 1,125 feet, foraminifera were found to be particularly numerous, and, for the most part, closely allied to species described by d'Orbigny from the Miocene of the Vienna basin.

A somewhat detailed examination of the strata overlying the green-sand deposits along their eastern margin reveals certain prevailing types of sedimentation that can be traced for long distances. The micaceous clay mentioned by Prof. Cook is practically continuous across the State, having been found in natural exposures and by boring at frequent intervals. Micaceous and pure quartzose sands likewise accompany the clays, and in several localities, one found to the southeast of Centreville, they are interbedded. Extensive deposits of sand characterize the Miocene. Much that has been termed "glass sand" should be referred to this formation. One of the best points to see the contact of the Miocene with the Upper Marl Bed is at Farmingdale, a few miles to the south of the area mapped. Here the Upper Marl Bed is overlaid by one foot of gravel, the larger particles reaching about one-half inch in diameter and nearly spherical in form. Overlying the gravel are six or eight feet of dark, micaceous clay, astringent to the taste. It is here somewhat lignitic and contains casts of

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* Philadelphia Acad. Nat. Sci. Proc, 1887, pp. 340–342.

marine mollusca, the most common form being an undetermined species of *Crassatella*. Overlying the dark clay are five or six feet of grayish-colored clays and clayey sands. On the south bank of the Manasquan river, to the south of Farmingdale, the hills are largely formed of the sands and sandy clays.

Fig. 8.

Farmingdale Marl Pit, showing Upper Marl Bed overlaid by Miocene.

Within the area represented upon the map the Neocene deposits are found only in the southern portion. There is an excellent section to the southeast of Centreville, above Poplar creek, where the dark clays rise nearly to the top of the higher levels. The basal portions of the Hominy hills are formed largely of the Neocene quartzose sands, while outliers of the same are found farther to the west, in the vicinity of Freehold.

The Neocene strata of New Jersey have, according to Prof. Heilprin,* afforded the following molluscan forms. Most of them are derived from the Shiloh marls:

BRACHIOPODA.

Discina lugubris Conrad.

LAMELLIBRANCHIATA.

Ostrea virginica (*O. Mauricensis*) Gmelin.
" *percrassa* Conrad.
Pecten Humphreysii Conrad.
" *Madisonius* Say.
" *vicenarius ?* Conrad.
Anomia ephippium ? Lea.
Plicatula densata Conrad.
Mytilus inflatus Tuomey and Holmes.
" *incrassatus* Conrad.
Mytiloconcha incurva Conrad.
Lithodomus subalveatus Conrad.
Perna maxillata Lamarck.
Arca centenaria Say.
" *marylandica* Conrad.
" *subrostrata* Conrad.
" *idonea ?* Conrad.
" *lienosa ?* Say.
Pectunculus lentiformis Conrad.
Nucula obliqua Say.
Yoldia limatula Say.
Astarte compsonema Conrad.
" *obruta* Conrad.
" *perplana ?* Conrad.
" *Thomasii* Conrad.
" *distans* Conrad.
Crassatella melina Conrad.
Cardita granulata Say.
Carditamera arata Conrad.
Carditamera aculeata Conrad.
Lucina crenulata Conrad.
" *trisulcata ?* Conrad.
Mysia parilis Conrad.
" *sp. ?*
Chama congregata Conrad.
Cardium laqueatum Conrad.
Cytherea Sayana Conrad.
Venus Ducatellii Conrad.
" *plena* Conrad.
" *latilirata* Conrad.
" *sp. ?*
Mercenaria cancellata Gabb.
Artemis acetabulum Conrad.
Mactra lateralis Say.
" *ponderosa ?* Conrad.
Donax variabilis Tuomey and Holmes.
Tellina shilohensis.
" *declivis* Say.
" *peracuta* Conrad.
Tellinella capillifera Conrad.
Amphidesma subreflexa Conrad.
Thracia myæformis Conrad.
Anatina alta Conrad.
Corbula elevata Conrad.
" *idonea* Conrad.
Saxicava parilis Conrad.
" *incita. ?*
Teredo sp. ?

GASTEROPODA.

Murex shilohensis Heilprin.
Turbinella Woodi Gabb.
Cantharus cumberlandianus Gabb.
Fulgur scalarispira Conrad.
Nassa trivittata Say.
Columbella communis Conrad.

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* Philadelphia Acad. Nat. Sci. Proc., 1887, pp. 397–405.

Terebra curvilirata Conrad.
Triforis terebrata Heilprin.
Cancellaria sp.?
Marginella sp.?
Pleurotoma pseudeburnea Heilprin.
Natica hemicrypta Gabb.
" *catenoides?* Wood.
Turbo eboreus Wagner.
Carinorbis (*Delphinula*) *globulus* H. C. Lea.
Turritella æquistriata Conrad.
" *cumberlandia* Conrad.
" *secta* Conrad.
" *plebeia* Say.
Trochita centralis Conrad.
Crucibulum costatum Say.
Crepidula fornicata Say.
" *plana?* Say.
Fissurella Griscomi Conrad.

In addition to the molluscan types, many species of Diatoms, Foraminifera, Crustacea, and Vertebrata have been obtained.

SUMMARY.

The Coastal Plain series of New Jersey affords a most diversified sequence of deposits, in which both shallow and deep-water types of sedimentation are prominently represented. The most characteristic feature is the unprecedented development of greensand, which at times occurs in beds of exceptional purity and many feet in thickness.

The basal division of the coastal deposits is known as the Raritan formation and consists of a series of 347 feet of clays and sands, the former predominating in the lower, the latter in the upper portion of the formation. The organic remains found in the strata are largely of plant origin, the few animal forms consisting chiefly of molluscan types, poorly preserved, and indicating brackish-water conditions. The plants afford many forms identical with the Potomac formation of more southern latitudes, so that the identity of the Raritan formation with the Potomac is indicated. The Raritan formation is unconformable to the red shales of the Jura-Trias, upon which it rests along its western border. To the east it is conformably overlaid by later deposits, and since the conditions gradually changed, no sharp line of demarcation is found. The Raritan formation affords the valuable sands and clays that are worked so extensively in the vicinity of Amboy and Woodbridge.

Overlying the Raritan formation conformably is the Clay Marl formation. The lower layers are not readily separated from the deposits of the Raritan formation with which they come in contact. The Clay Marl strata were formed under distinctly marine conditions, as shown by the fossils and characteristic deposits. The fossils have only been

found hitherto at a few points. They are in the main identical with the forms from the overlying Lower Marl Bed. Locally, also, the conditions were favorable for the production of greensand, but except in a few instances the glauconitic layers occur only as thin seams irregularly interspersed through the strata. The Clay Marl formation is estimated to reach 270 feet in thickness. The clays are extensively used for brickmaking.

The Lower Marl Bed is one of the most striking horizons in the coastal series. It varies from thirty to fifty feet in thickness and is composed largely of greensand, at times, however, mixed with clayey and sandy materials. The Lower Marl Bed is the most fossiliferous zone in the greensand series. More than 200 forms have been described. The Lower Marl Bed has been extensively dug as a fertilizer, while the soils developed upon its surface are among the richest in the State.

The Red Sand is much more highly quartzose than the underlying Lower Marl Bed. Glauconite is seldom absent, but is nowhere present in such large quantities as in the latter formation. Extensive oxidation has changed the grains of glauconite for the most part from a green to a red color. The lower layers are often characterized by a dark, sandy zone, while a hardened, clayey band, more or less green in color, caps the formation. The estimated thickness of the Red Sand formation is 100 feet. The fossils are not numerous, but so far as examined are mainly identical with those of the Lower Marl Bed.

The Middle Marl Bed overlies the Red Sand formation conformably. It is a pronounced greensand in the lower part, with argillaceous layers frequently developed at the base, while the upper portion is highly calcareous. Hard bands of limestone are found at the latter horizon in many sections of the State. Directly underlying the limestone zone are two very persistent and highly-fossiliferous layers, the upper of the two containing *Terebratula Harlani*, the lower *Gryphœa vesicularis*. The thickness of the Middle Marl Bed is estimated at forty-five feet.

The Upper Marl Bed embraces, in the present report, in addition to the strata hitherto so called, the "yellow sand" of Prof. Cook. The latter is so intimately associated with the greensand deposits of the Upper Marl Bed as not to warrant its separation as an independent formation. It is often less glauconitic than the "greensand" and

"ash marl" of the Upper Marl Bed of Prof. Cook with which it is now associated. These three divisions are placed together in the present report under the name of the Manasquan Marl, as the lower member of the Upper Marl Bed. The Manasquan marl is a greensand throughout, quartzose in the lower portions, where it was known as the "yellow sand," argillaceous in the upper portions, where it was known as the "ash marl." The more glauconitic layers have been highly prized for their rich fertilizing marls, which have been extensively dug in southern Monmouth county. The Manasquan marl is estimated to attain a thickness of sixty-five feet. The Shark river marl, which was described by Prof. Cook under the name of the "blue marl," is placed as the upper member of the Upper Marl Bed. It is a compact greensand, which in its upper portion is consolidated into firm, stony layers. It is conformable with the Manasquan marl wherever observed. It is very rich in fossils, which are considered Eocene in age, although there are no forms in common with the Eocene strata of Maryland or Virginia, and comparatively few that are held to be identical with Eocene species from other localities. As the specimens are all casts there is some uncertainty as to their proper identification. The Shark river marl is about twelve feet in thickness.

The Miocene is extensively developed in New Jersey. Fossils have only been found at a few points, but sufficient in number to indicate a series of deposits several hundred feet in thickness and many square miles in surface exposure. The lack of fossils is doubtless largely to be accounted for on account of the prevalence of coarse, shallow-water deposits, which are ill adapted for the preservation of organic remains.

A review of the structural and stratigraphical relations of the deposits of the coastal series of New Jersey shows complete conformity from the bottom of the Raritan formation to the top of the Upper Marl Bed, while no wide-reaching dislocations of the strata have been observed at any point. The strike follows a nearly continuous trend of N. 50° E., while the dip is twenty-five to thirty feet in the mile toward the southeast. Overlying the Upper Marl Bed unconformably is the Miocene, which possesses the same general structural and stratigraphical features as the earlier members of the series.

ORIGIN OF GREENSAND.

INTRODUCTION.

The presence of greensand in the geological deposits of the globe was early recognized, and Alexander von Humboldt, in 1823, mentions its occurrence in the Carboniferous of Hungary, the Bunter Sandstein (Trias), and Quader Sandstein (Cretaceous) of Germany, and Calcaire Grossier (Eocene) of France. Its chemical composition had been determined prior to this by Berthier,* who made an analysis of the greensand of the Calcaire Grossier in 1821. The analysis of Berthier became generally accepted as typical of greensand and was adopted in almost all works on geology and mineralogy. As geological investigations extended to more distant portions of the globe, new deposits were discovered, and the wide distribution of greensand in the earth's strata became recognized.

It was not, however, until the microscope began to be used in geological investigations that any progress was made toward explaining its origin. Prof. J. W. Bailey, in 1845, announced the discovery of great numbers of foraminifera in various Cretaceous and Tertiary marls of the United States, and called attention to the occurrence of casts of the shells in the Eocene at Fort Washington, Maryland. He stated in this paper that he had forwarded the materials which he had collected to Prof. Ehrenberg, of Germany, for fuller investigation. In 1854 and 1855 Ehrenberg presented the results of his work in a series of communications † to the Royal Academy of Sciences of Berlin, and was the first to show the connection between greensand and the foraminifera. He had somewhat earlier shown that the silica forming the shells of the foraminifera in the chalk was due to pseudomorphism of an original calcareous substance, and Mantell ‡ had also referred to the filling of the chambers of the same with calcite, silica, and silicate of iron.

Ehrenberg, in this early and important series of contributions, states that "the formation of the greensand consists in a gradual filling up of the interior space of the minute bodies with a green-colored, opal-

* Annales des Mines, ser. 1, VI., 1821.

† Abhandl. d. k. Akad. d. Wissenschaften zu Berlin, 1855, pp. 85-176.

‡ Phil. Trans., 1846, p. 466.

like mass, which forms therein as a cast. It is a peculiar species of natural injection, and is often so perfect that not only the large and coarse cells but also the very finest canals of the cell walls and all their connecting tubes are thus petrified and separately exhibited. By no artificial method can such fine and perfect injections be obtained." The author describes the characteristic features of greensand specimens which he had obtained from numerous localities in Europe and America.

Following out the observations of Ehrenberg, Prof. J. W. Bailey * made an extensive examination of specimens of Cretaceous and Tertiary deposits from many portions of America in the hope of finding further evidence of the relations existing between greensand and the foraminifera. Among other materials he examined specimens of greensand from Mullica Hill and Mt. Holly, in this State, in which were found numerous casts of foraminifera. The great interest of this paper centers, however, in the announcement first made by Prof. Bailey that the formation of greensand is likewise taking place on the floor of existing seas and under the same conditions that existed in past geological ages. He found in these marine deposits the foraminifera and other forms reported by Ehrenberg from geological strata. These conclusions were based on material described by Pourtales † in 1853 and obtained from soundings made by the United States Coast Survey in the exploration of the Gulf Stream, together with additional material examined by Bailey himself from the same source. The specimen first reported by Pourtales came from a depth of 150 fathoms in latitude 31° 32′ N., longitude 79° 35′ W. Concerning it Pourtales says that it is "a mixture in about equal proportions of Globigerina and black sand, probably greensand, as it makes a green mark when crushed on paper." Bailey states further in regard to it that he has "found that not only is greensand present at the above locality but at many others, both in the Gulf Stream and Gulf of Mexico, and that this greensand is often in the form of well-defined casts." He says again: "The species of Polythalamia [Foraminifera], whose casts are thus preserved, are easily recognizable as identical with those whose perfectly-preserved shells form the chief part of the soundings. That these are of recent species is proved by the fact that some of them still retain their brilliant red coloring, and that they leave distinct remains of their soft

* Boston Soc. Nat. Hist. Proc., Vol. 5, 1856, pp. 364 368.

† U. S. Coast Survey Rep., 1853, App., p. 83.

parts when treated with dilute acids. It is not to be supposed, therefore, that these casts are of extinct species washed out of ancient submarine deposits. They are now forming in the muds as they are deposited, and we have thus now going on in the present seas a formation of greensand by processes analogous to those which produced deposits of the same material as long ago as the Silurian epoch, * * * and it should also be stated that many of the grains of greensand accompanying the well-defined casts are of wholly unrecognizable forms, having merely a rounded, cracked, lobed, or even coprolitic appearance. * * * The fact, however, being established beyond a doubt, that greensand does form casts in the cavities of various organic bodies, there is a great probability that all the masses of this substance, however irregular, were formed in connection with organic bodies, and that the chemical changes accompanying the decay of the organic matter have been essentially connected with the deposits in the cavities of green and red silicates of iron and of nearly pure silica." The fact that the siliceous organisms which accompany the foraminifera do not form similar casts is particularly commented on. The author, however, states that the researches of Ehrenberg and himself show that other calcareous organisms besides the foraminifera may serve as moulds for the greensand.

From the soundings made by the United States Coast Survey in 1867 along the American coast, Pourtales examined, among other materials obtained, the greensands. He gives in his report a description of the various stages in the formation of glauconite. In this connection he says: " We find, side by side, the tests perfectly fresh, others still entire, but filled with a rusty-colored mass, which permeates the finest canals of the shells like an injection. In others, again, the shell is partly broken away and the filling is turning greenish, and finally we find the casts without trace of shell, sometimes perfectly reproducing the internal form of the chambers; sometimes, particularly in the larger ones, cracks of the surface or conglomeration with other grains obliterate all the characters. They even coalesce into pebbles in which the casts can only be recognized after grinding and polishing." The author mentions the occurrence of greensand at depths of 50 to 100 fathoms off the coasts of Georgia and South Carolina.

In more recent years the vessels sent forth by the various governments of Europe and our own to dredge and take soundings at the greatest depths have added much to our knowledge of the distribution

and character of greensand on the floors of existing seas. Of by far the greatest importance among such voyages is the expedition of the Challenger, sent out by the British government in the years 1872–76. The scientific work was in charge of able and competent men, who, in the years since the close of the voyage, have had associated with them the specialists of all lands for the fuller study of the wonderfully rich materials that were collected. As all the greater oceans of the globe were visited and portions of the coasts of every continent approached, the most varied materials were obtained. One of the most valuable results connected with this important expedition has been the great light thrown upon our knowledge of the distribution and origin of greensand. The volume dealing with this and other marine deposits appeared only a short time since under the joint authorship of Prof. John Murray and Prof. A. F. Renard. Their views will be constantly referred to and often closely followed in the following pages.

CLASSIFICATION OF MARINE DEPOSITS IN GENERAL.

In order to understand more fully the conditions under which the greensand deposits of the existing oceans are formed, it is necessary to speak briefly in regard to the formation of deposits in general.

It has been estimated that the continents approximately cover two-sevenths of the surface of the globe, while bordering the continents and extending on an average 200 miles from the coasts, and reaching on an average two miles in depth, is an area of land-derived materials which covers another seventh of the earth's surface. It is in this zone that the sediments of past geological ages are generally considered to have accumulated. Prof. Murray speaks of it as the Transitional Area.

The four-sevenths of the earth's surface remaining are covered by pelagic deposits of slow accumulation and of which we have no trace in the strata of the continents. As it is only with the Transitional Area that we shall have to concern ourselves, it will be unnecessary to discuss in detail the Pelagic Area. Its deposits are derived chiefly from the remains of organisms and the decomposed materials of submarine and subaërial volcanic eruptions. When the remains of calcareous organisms are the prevailing constituent the deposit is known as either a Pteropod Ooze or a Globigerina Ooze, or when siliceous organisms characterize the accumulation it is known as either a Diatom Ooze or

a Radiolarian Ooze, while the preponderance of decomposed volcanic debris produces a Red Clay, the most widely-distributed deposit over the ocean floor. The pelagic deposits are estimated to cover nearly 115,000,000 square miles of the earth's surface.

Within the Transitional Area the deposits may be classed in three zones, the Littoral, the Shallow-water, and the Deep-water.

The Littoral Zone includes the deposits formed between high and low-water marks and produced largely by the direct action of the waves upon the adjoining coasts. They are composed of the coarser materials, such as bowlders, gravel, and sand, although in sheltered places mud may accumulate. To these may be added at times the remains of organisms that live near the coasts. As compared with the whole extent of the Transitional Area the Littoral Zone is small. It is estimated to cover 62,500 square miles.

The Shallow-water Zone is found between low-water mark and the 100-fathom line, and comprises deposits similar in character to the Littoral Zone, but gradually becoming finer as the distance from the coast increases. As the outer limit is approached the sediments become more and more like the deep-water deposits, into which they finally grade. With the gravels, sand, and muds of this zone organic remains become mixed in greater or less amounts, at times comprising the larger part of the deposit. The area of the sea floor estimated to be covered by the shallow-water deposits is 10,000,000 square miles.

The Deep-water Zone, in which deposits of a terrigenous character are forming, extends from the 100-fathom line to an average depth of two miles. Here, except accidentally, the deposits are very fine and the accumulation of material exceedingly slow. Fine sands, clays, muds, and organic oozes are the most characteristic deposits, and in general mechanical changes are absent. The conditions are very uniform throughout the zone. The area covered by these deep-water deposits is estimated at about 18,000,000 square miles.

The deposits of the Deep-water Zone are classed under five heads, viz., Blue Mud, Red Sand, Green Mud and Sand, Volcanic Mud and Sand, Coral Mud and Sand.

The most widely distributed of these deposits is the Blue Mud, which is generally found in the deeper water surrounding the continents, and is composed of the finer materials of land-derived origin mixed with greater or less quantities of organic debris. The blue color is accounted for by the presence of organic matter and sulphate

of iron. Blue Mud is estimated to cover 14,500,000 square miles of the sea floor.

The Red Mud is chiefly confined to the Brazilian coast, and takes largely the place of Blue Mud. Its red color is thought to be due to the great amount of hydrous peroxide of iron brought to the sea by the rivers, and which cannot be reduced by organic matter, as in the case of the Blue Mud. The area covered by it is, however, small, and is estimated at about 100,000 square miles.

The Volcanic Mud and Sand are formed near islands or coasts of volcanic origin, the deposits consisting of the debris of the rocks of the land. They may be much mingled with materials of organic origin when accumulation is slow. They are estimated to cover an area of about 600,000 square miles of the Deep-water Zone.

The Coral Mud and Sand are formed of the debris of coral reefs and are found spread for great distances over the sea floor along the coasts where coral growth takes place. They are estimated to cover over 2,500,000 square miles of the ocean bed.

The Green Mud and Sand, which are the especial subjects of this chapter, will be described in the following pages in greater detail.

CHARACTER AND MANNER OF OCCURRENCE OF GREENSAND.

The green mud and sand are land-derived sediments which are characterized by the presence of greater or less amounts of a greenish mineral substance known as glauconite, which is secondary in origin, and occurs either in the form of irregular grains or as clearly-defined casts of the calcareous organisms which had accumulated on the sea floor. It will be more fully characterized in the following pages. Mixed with the glauconite is also a greenish or brownish amorphous matter, which is considered by Murray to be in part at least of organic origin, since it becomes black when heated on platinum foil, leaving an ash which ultimately becomes brown on account of the presence of oxide of iron.

The mineral particles associated with the glauconite are chiefly those which are characteristic for terrigenous deposits. They are of different kinds and occur in varying proportions, frequently forming a large part of the whole deposit. They are angular, in this respect differing from the glauconite, while they vary in diameter from 0.06 to 0.20 mm., being 0.13 mm. upon the average. Among the more common minerals are quartz, feldspar, hornblende, magnetite, augite, zircon,

epidote, tourmaline, and garnet, together with fragments of the continental rocks, such as gneiss, mica schist, granite, diabase, &c.

Mingled with the green sand and mud are varying amounts of carbonate of lime derived from the shells of organisms. In the specimens of mud collected by the Challenger expedition the average was 25.52 per cent., of which 17.53 per cent. was found to be due to foraminifera. In the sands the average was 49.98 per cent., of which 37 per cent. was derived from foraminifera. Siliceous organisms were also found, affording in the case of the muds on the average 13.67 of silica, and in the case of the sands 8 per cent.

Phosphate of lime is a constant accompaniment of greensand deposits. It occurs in small amounts and often in nodular form.

Fragments of volcanic rocks and minerals, which in greater or less amounts find their way to all portions of the sea floor, are found mingled in the greensand beds, although greensand does not occur in true volcanic sediments.

Although foraminifera and other calcareous organisms are found in the green muds and sands, in fact are necessary for their formation, still the globigerina and pteropod oozes and the coral muds and sands do not contain a trace of glauconite, except in the presence of mineral particles of continental origin. The occurrence of glauconite in red clay or diatom and radiolarian oozes may likewise be always explained on account of the accidental presence of land-derived materials.

Murray and Renard refer to the occurrence of glauconite off the coast of Africa and Australia and towards the polar regions in red clays which "contain apparently wind-borne or ice-borne particles of quartz, orthoclase, white mica, epidote, zircon, and fragments of gneissic and granitic rocks; and it may be urged that glauconite has been transported to these deposits at the same time or had been formed in consequence of the association with the above minerals. The view that it has been found *in situ* is probably the correct one, for we have seen that it is thus formed in shallower water deposits, like the greensands, where its associations are much more distinctly marked and its progressive development more easily traced."

Glauconite is also found to be absent from the red muds which cover the sea floor off the coast of Brazil and in the Yellow sea. Although these deposits are of land-derived origin, they differ from the terrigenous deposits in the great amount of hydrous iron oxide present in the sediments. The iron is in a higher state of oxidation than in

the green and blue muds and sands, where the conditions are most favorable for the production of glauconite, but how this interferes with its formation has not been satisfactorily explained.

Finally, glauconite is found in those deposits of land-derived origin in proximity to the shore, where the sediments have been extensively decomposed by long exposure to the marine waters. This could only take place where deposition is relatively slow and mechanical disturbance slight.

From what has just been stated it will be seen that the portions of the floor of the ocean best fitted for the production of glauconite are found adjacent to the coast and along the higher parts of the continental slope where land-derived materials are deposited in moderate amounts. The production of glauconite seldom reaches to greater depths than 900 fathoms and most commonly takes place near the boundary line between the Shallow-water and Deep-water Zones. The entrance of large rivers into the sea or the prevalence of strong currents would tend to interfere with its formation, so that the area of distribution of glauconite is seldom continuous for great distances.

Since the presence of glauconite characterizes the greensand deposits, it is with its character and manner of occurrence that we have chiefly to concern ourselves. In the investigation of the materials collected by the Challenger it was found that the individual grains of glauconite seldom exceed 1 mm. in diameter, although they become at times agglomerated into nodules several centimeters in diameter by means of a phosphatic cement. In his investigation of the greensand obtained from the Agulhas bank by the Gazelle, Gümbel found that the size of the grains varied from $\frac{1}{15}$ to 1 mm., the average being $\frac{1}{2}$ mm.

The grains are always more or less rounded and at times mammillated, with irregular surface outline. They are generally black or dark green in color but become deeper green upon being crushed. The surface of the grains is sometimes covered with fine punctures, while at other times it is smooth and shining. Some of these glauconitic grains are distinct internal casts of the foraminifera and other calcareous shells, but more often they only reproduce indistinctly the form of the chambers or show no definite connection with the organisms in which they originated. Sometimes the casts do not possess the typical deep-green color and appearance of glauconite but are a of fainter green or even have a brownish or yellowish tinge.

Dana, in his Manual of Mineralogy, gives the hardness of glauconite

as 2 in the scale in which the softest mineral is placed at 1 and the hardest at 10. Its specific gravity is stated by the same author to vary from 2.29 to 2.35.

Samples of the typical greensand collected by the Challenger were hardened and cut into thin sections, so that the structure could be examined by means of the microscope. The various mineral substances hitherto mentioned as entering into the formation of greensand could be in most instances satisfactorily detected. It was found that every gradation existed between shells in which the hollow spaces were empty to those completely filled. At times the chambers were coated or partially filled with a brownish, semi-transparent substance, at other times one or two of the chambers only were filled, while the others were empty. In some instances it was observsd that the smaller chambers were filled with a green substance, while in the larger ones the material was yellowish or brownish in color. Some of the grains seemed to have burst the shells in their continued growth until finally the form of the chamber was lost in the cast, which had an irregular outline.

The grains of glauconite were transparent when cut into thin sections and were in the main homogeneous, presenting no special structure with ordinary light. Although normally green and of the same color throughout, some of the grains were found to be a little deeper on the edges, while others, probably due to decomposition, were reddish or brownish. Between crossed nicols the glauconite shows aggregate polarization, extinction never taking place at the same time throughout the entire section. According to Murray and Renard it presents itself in the following manner: "The glauconitic particles have indefinite contours and appear dotted with little points united the one to the other and polarizing with a bluish-green tint. These deep-colored points are detached from a base generally yellow or yellowish green in color. The dotted parts, of a bluish-green color, more or less deep, form a rather close network, which is very vague as to its contours. The outlines of the sections of glauconite are not clearly defined and the relief is feeble. Glauconite is never seen with a zonary structure, except in cases where alteration has commenced or where it shows, as previously mentioned, a border of a deeper color following the external contours; nor does it present a fibro-radiate or a concretionary structure. Sometimes the microscope shows vaguely that around the grains there is a colorless zone of slight thickness, in which the arms of the

cross of spherolithic concretions may be observed. Microscopic examination appears to show that the substance of glauconite itself is quite homogeneous. Sometimes, however, and especially when this mineral is inclosed in foraminiferous shells, it includes, in the largest or terminal chamber, mineral particles similar to those in the sediment in which it is formed; among these particles the most frequent are quartz and magnetite, the latter of which may be extracted by the magnet. There may also be seen a darkish powder, the feeble yellowish reflections of which might well indicate pyrites. In some sections the form of some of the chambers of the shells of foraminifera appears to be vaguely outlined. When the grains have undergone alteration these sections not only show a brownish or reddish tint, from the presence of hydrate of iron, but this alteration is frequently accompanied by cracks traversing the glauconite in many directions. The sections of the glauconitic casts appear in the preparations with all the characteristic contours of the organisms in which they have been moulded, and the microscopic details apply equally to these, at least when they have taken on the characteristic green color of glauconite."

CHEMICAL COMPOSITION AND MODE OF FORMATION OF GREENSAND.

Numerous analyses of greensand have been made since Berthier first analyzed the green grains of the Calcaire Grossier of the Paris basin. Very wide differences, however, are to be found in these analyses, doubtless due in a large measure to the difficulty of obtaining the glauconite in an absolutely pure state. Its association with numerous other substances, together with the frequent admixture in the grains themselves of mineral particles of a foreign nature, makes it very difficult, if not quite impossible, to obtain its true chemical composition. In the following table will be found some of the more important analyses which have been made of greensand and of the isolated glauconite grains:

Analyses of Greensand.

No.	SiO_2	Al_2O_3	Fe_2O_3	FeO*	CaO	MgO	K_2O	Na_2O	H_2O	Total.
1	46.3	7.6	....	22.3	3.0	6.0	.. ..	....	15.0	100.2
2	40.0	1.1	....	24.7	3.3	16.6	1.7	....	12.6	100.0
3	53 46	5.0	....	21.78	.. ..	6.21	8.79	....	4.76	100.0
4	47.6	4.2	21.6	3.0	2.5	1.4	4.6	....	14.7	99.6
5	50.8	6.7	21.8	3.1	tr.	4.2	3.1	....	9.8	99.5
6	49.1	7.1	23.6	3.2	.. ..	....	5.75	....	10.1	98.85
7	50.42	4.79	19.90	5.96	3.31	2.28	7.87	....	5.28	99.81
8	46.91	2.64	23.06	7.04	2.95	4.40	7.31	....	4.71	99.02
9	49.09	15 21	10.56	3.06	0.55	2.65	6.05	1.21	11.64	100.02
10	46.90	4.06	27.09	3.60	0.20	0.70	6.16	1.28	9.25	99 24
11	56.62	12.54	15.63	1.18	1.69	2.49	2.52	0.90	6.84	100.41
12	50.85	8.92	24 40	1.66	1.26	3.13	4.21	0.25	5.55	100.23
13	51.80	8.67	24.21	1.54	1.27	3.04	3.86	0.25	5.68	100.32
14	55.17	8.12	21.59	1.95	1.34	2.83	3.36	0.27	5.76	100.39
15	27.74	13.02	39.93	1 76	1.19	4.62	0.95	0.62	10.85	100.68
16	50.70	8.03	22.50	....	1.11	2.16	5.80	0.75	8.95	100.00

Nos. 1, 2. BERTHIER,† green grains from the Eocene (Calcaire Grossier) of the Paris Basin.

No. 3. VON D. MARK,‡ glauconite from the Cretaceous marls of Westphalia.

No. 4. HAUSHOFER, C.,§ green grains from the Cretaceous greensand of Bavaria.

No. 5. HAUSHOFER, C., glauconite from the Jurassic limestone (Malm) of Bavaria.

No. 6. HAUSHOFER, C., glauconite from the Triassic limestone (Muschelkalk) of Bavaria.

No. 7. DEWALQUE,|| glauconite grains from the Pliocene sands of Belgium.

No. 8. VON BAMBERGER,¶ glauconite from the Miocene of Germany.

No. 9. HEDDLE,** glauconite from the Jurassic (Oolite) of Scotland.

No. 10. GÜMBEL,†† glauconite from the Agulhas bank, south of the Cape of Good Hope.

Nos. 11–14. MURRAY and RENARD,‡‡ greensand from the Australian coast, off Sydney, at a depth of 410 fathoms.

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* In the earlier analyses the distinction was not made between the ferrous and ferric oxides.

† Annal. d. Mines, 6, 1821, p. 459.

‡ Zeitschr. d. deutsch. geol. Gesellsch., 8, 1856, p. 135.

§ Journ. f. pract. Chemie, 97, 1866, p. 353.

|| Ann. d. l. Soc. geol. de Belg., 2, 1877, p. 3.

¶ Tschermak Min. Mittheil., 1877, p. 271.

** Royal Soc. Edinburg, Trans. 29, 1879, p. 79.

†† Sitzb. d. k. b. Akad. d. Wissensch., 16, 1886, p. 437.

‡‡ Repts. Challenger Expedition, Deep-sea Deposits, 1892, p. 387.

No. 15. MURRAY and RENARD, greensand from near Raine island, to the southeast of Cape York, Australia, at a depth of 155 fathoms.
No. 16. HUNT, T. STERRY,* glauconite from the Cretaceous of New Jersey.

Numerous analyses are also given of the New Jersey greensands in the annual reports of the State Geologist, but no attempt has been made in them to separate the glauconitic grains from the other ingredients of the greensand marl. A few typical analyses are given below, but a somewhat different method is observed in determining the various substances than in the analyses previously cited.

* Min. Physiol. and Physiog., 1886, p. 198.

Analyses of New Jersey Marl from Monmouth and Middlesex Counties.

Formation.	Clay Marl.		Lower Marl.							Middle Marl.		Upper Marl.	
Number of Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13
Phosphoric acid	1.15	0.58	1.51	1.14	2.18	0.84	0.38	1.14	1.20	0.19	0.50	6.87	3.73
Sulphuric acid	1.28	....	2.40	0.14	....	0.12	0.20	0.31	....	0.41	0.34	3.12	2.44
Silicic acid and sand	34.50	45.50	55.69	38.70	43.70	52.07	53.10	38.70	36.70	51.15	47.50	44.68	49.68
Potash	1.54	3 79	5.27	3.65	3.82	6.46	3 78	4.47	3.10	7.08	5.29	3.97	4.98
Lime	2.52	1.51	0.65	9.07	8.85	1.01	....	....	1.56	0.49	0.56	4.97	4.14
Magnesia	2.15	2.20	0.79	1.50	2.33	1.53	0.70	1.21	2.60	2.02	2.70	2.97	0.47
Alumina	6.00	5.80	6.61	10.20	25.00	6 96	6.30	30.67	43.58	8.23	8.60	6.04	28.71
Oxide of iron	31.50	24.50	21.63	18.63		21.55	15.39			23.13	20.52	18.97	
Water	18.80	15.40	8.85	10.00	9.21	9.31	8.64	11.22	10.62	6.67	13.57	8.63	5.54
Carbonic acid	....	....	....	6.14	5.40	....	....	....	....	....	....	....	....
Carbonate of lime	....	....	....	....	....	....	12 10	13.91	....	....	....	....	....
Total	99.43	99.18	102.40	99.16	100.49	99.85	100.59	99.65	99.36	99.37	99.58	99.32	99.69

No. 1. Clay marl from near Mattawan.
No. 2. Clay marl from Matchaponix creek, three miles south of Spottswood.
No. 3. Lower marl from Navesink Highlands.
No. 4. Lower marl from north shore of Navesink river at Red Bank.
No. 5. Lower marl from Hop brook, near Marlboro.
No. 6. Lower marl from northwest slope of Mount Pleasant hills.
No. 7. Lower marl from north of Freehold.
No. 8. Lower marl from indurated layer at Tinton Falls.
No. 10. Middle marl from near Eatontown.
No. 11. Middle marl from southeast of Freehold.
No. 12. Upper marl (Manasquan) from Poplar.
No. 13. Upper marl (Shark river) from Shark river.

Concerning the mode of formation of glauconite there is much that is difficult to understand. The most satisfactory statement is given by Murray and Renard in their report upon the deep-sea deposits obtained by the Challenger expedition. It is given in full in the following pages:

"While it must be admitted that we have arrived at certain definite and satisfactory conclusions as to the conditions under which glauconite is found in our present seas, as well as in geological formations, we are far from having at our disposal all the facts necessary for a complete explanation of its mode of origin. So many possible reactions may take place in the deposits being laid down in existing seas that it is difficult to be certain that any one of them is necessarily the one which has been followed in the deposition of this silicate in the terrigenous deposits. The explanations that are given with reference to the formation of glauconite must then be more or less hypothetical; it is not to be wondered at that its origin has remained for a long time enigmatical, and that the researches of numerous mineralogists up to the present time have not led to any very definite results. Two principal opinions have been expressed.* Before the time of Ehrenberg attention had not been called to the remarkable fact that the grains of glauconite sometimes carried the impress of the calcareous organisms in whose cavities they were moulded. He concluded that this mineral was always formed through the activity of the creatures whose impress he had discovered.† This opinion was disputed by Reuss,‡ who believed

* For the various hypotheses as to the mode of formation of glauconite see Gümbel, "Ueber die Natur und Bildungsweise des Glaukonits," Sitzungsb. d. k. Akad. Munchen, Bd. xvi. Math. Phys. Kl., pp. 417-449, 1886.

† Ehrenberg, "Ueber den Grünsand und seine Erläuterung des organischen Lebens," Abh. d. k. Akad. Wiss. Berlin, 1855, Phys. Abh., pp. 85-176.

‡ Reuss, "Einige Bemerkungen über den Grünsand," Sitzungsb. d. k. Akad. Wiss. Wien. Bd., xl. Naturw. Kl., pp. 167-172, 1860.

that the grains of glauconite might be concretions, not moulds, formed outside of the foraminiferous and other shells, although he admits that some glauconitic grains are internal casts.

"From all that we have already stated in this chapter it appears certain that glauconite is principally developed in the interior of foraminiferous shells and other calcareous structures, and that all the transitions can be observed from chambers filled with a yellowish-brown mass to grains that have almost completely lost the impress of the organisms in which they were formed. From this fact, as well as from direct observations of the various constituents of the deposits, it is uncertain, and indeed little probable, that there are any minute grains of glauconite formed in a free state in the mud. We are therefore inclined to regard glauconite as having its initial formation in the cavities of calcareous organisms, although we have admitted above that some grains which might be regarded as glauconite appear to be highly-altered fragments of ancient rocks, or coatings of this mineral on these rock fragments. It appears that the shells are broken by the swelling out or the growth of the glauconite, and that subsequently the isolated cast becomes the center upon which new additions of the same substance take place, the grain enlarging and becoming rounded in a more or less irregular manner,* as in the case of concretionary substances like silica, for example, which forms moulds of fossils. We have already referred to the size of certain grains of glauconite found in geological formations; even if it be admitted that these large-sized grains are single individuals and not agglomerations of smaller grains, their occurrence might be explained by supposing them to have been formed in gastropods and other calcareous organisms larger than foraminifera.†

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*The increase by new additions of glauconitic material is indicated by the fact that in rare cases the glauconitic casts of foraminifera shells are found entirely enveloped by subsequent depositions of that mineral. In such a case it must be admitted that after the glauconite has broken the chambers of the foraminifera it has continued to play the role of center of attraction, and that the same matter has been continually deposited around this nucleus, thus causing the primitive form of the cast to disappear.

†Gümbel, who does not admit that certain grains of glauconite have been moulds in organisms, because of their large size and regular form, without trace of organic impress, suggests the following interpretation: He compares them with entoöliths and maintains that the gases disengaged by the decomposition of organic matters contained in the sediments where glauconite is formed, play a role in the formation of these glauconite granules. These gases are the hydrocarbons, carbonic acid and hydrosulphuric acid, which form bubbles of different dimensions that remain a long time in the muddy deposits and attach themselves to the grains of sand or aggregates of the mud, grouping themselves in a varied manner. At the surface of these bubbles reactions take place, provoked by the action of the gas upon the bodies held in solution in the sea-water, and a deposit of these bodies takes place there; it is usually carbonate of lime and silica that are thus deposited, and in this case glauconite would form the crust around the bubble. If this crust be formed it will be filled by intussusception in

"All the probabilities appear, then, to be in favor of the opinion that this silicate is formed originally in the cavities of organisms whose remains are deposited in the sediments of the sub-littoral and deeper zones of the sea. In the cavities and veins of rocks in process of decomposition green substances are frequently deposited, which for a long time were confounded with glauconite. But chlorite and green earth, for example, which are formed in this way, are minerals widely different from glauconite, and their formation may be easily explained by taking into account the mineralogical and chemical changes going on in these rocks. The initial stages of the formation of glauconite in these shells are, in all probability, due to the action of organic matter, which incontestably influences the precipitation of some mineral substances. In this case it must be admitted that the organic matters, or the sarcode elements of the organisms fallen from the surface or living on the bottom, ought to remain in the interior of the shells, at least temporarily. After the death of the organisms their shells are slowly filled with the fine mud in which they are deposited. The existence of this organic matter in these cavities and the absence of all other causes which might there induce the deposition of the silicates, in fact the constant association of these phenomena, appear to demonstrate the existenee of a relation of cause and effect. Formerly the role of organic matter in the formation of glauconite was specified by saying that it determined a reduction of the iron to the state of protoxide, but this interpretation is not admissible at the present time, for we have seen by the analyses that iron exists in glauconite in a state of peroxide. It may be urged that an infiltration pure and simple of the solution which forms glauconite into the cavities of the organisms takes place the same as in a geode. This solution, being attracted by the organic matter, may act upon the solid matters derived from the mud already inclosed in the cavities of the organisms. This, however, does not appear to be the most probable interpretation. In describing the microstructure of the glauconite grains it was pointed out that inclusions of mud, or quartziferous particles, grains of magnetite and other minerals were sometimes observed, and that these probably pre-existed in the shells before the development of the glauconite. It would appear that these inclosed materials must have undergone with time a molecular modification, whose final term is seen in the typical dark-green granules, presenting feeble double refraction and aggregate polarization and possessed of a greater hardness than the lighter-colored glauconitic casts of organisms, in which a more earthy nature may be

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the same solution that has given birth to the primordial glauconitic sphere. If they were bubbles of sulphuretted hydrogen, pyrites would be formed in them at the same time as the glauconite; if at the same time there were disengagement of hydrocarbons, there would be formed in the presence of iron, magnetite (by reduction) similar to that found inclosed in the grains of glauconite. We felt bound to notice these views, but everything connected with them appears very hypothetical.

observed. It is certain that very fine mud is washed into the Globigerina shells and may penetrate through the foramina. If we admit that the organic matter inclosed in the shell and in the mud itself transforms the iron in the mud into sulphide, which may be oxidized into hydrate, sulphur being at the same time liberated, this sulphur would become oxidized into sulphuric acid, which would decompose the fine clay, setting free colloid silica, alumina being removed in solution; thus we have colloid silica and hydrated oxide of iron in a condition most suitable for their combination. To explain the presence of potash in this mineral we must remember that, as we have shown when speaking of the formation of palagonite under the action of sea-water, there is always a tendency for potash to accumulate in the hydrated silicate formed in this way, and, as we have stated before, this potash must have been derived from the sea-water.

"If we recall the observations with reference to the geographical distribution and mineralogical and lithological associations, it seems possible to suggest, with a considerable degree of certainty, the relative abundance of potash in the deposits where glauconite is forming. It was pointed out that glauconite was always associated with terrigenous minerals, and in particular with orthoclase, more or less kaolinized, and white mica, and with the debris of granite, gneiss, mica-schists and other ancient rocks. We cannot fail to be struck with these relations, for it is just those minerals and rocks that must give birth by their decomposition to potassium, derived from the orthoclase and the white mica of the gneisses and the granites.* The minute particles of these rocks and minerals, which make up a large part of the muddy matters settling on the bottom beyond the mud-line around continental shores, would readily yield under the action of sea-water the chemical elements that are deposited in the form of glauconite in the chambers of foraminifera and other calcareous organisms."

DISTRIBUTION OF GREENSAND IN GEOLOGICAL FORMATIONS.

That glauconite is very widely represented in the geological formations of the earth's crust has been long recognized, and many writers upon geology have described, in greater or less detail, the individual occurrences. Some of the oldest of the stratified rocks have been found to have greensand, and from the Cambrian to the present time all the leading divisions of the geological column have afforded it in greater or less amounts.

* It has been shown, in fact, by Guignet and Telles, that the water of the bay of Rio Janeiro contains a large amount of potassium salts, evidently due to the presence of ancient rocks in this bay. (See Comptes Rendus, tom. lxxxiii., p. 919, 1876.)

In America it has been found in the Potsdam sandstone of the Cambrian in Wisconsin, Minnesota and Tennessee and in the Quebec Group of the Silurian at Point Lewis and the Island of Orleans in Lower Canada. The Carboniferous of Ohio has also been shown to have glauconite in small amounts.

In Europe similar deposits are known in the earlier Palæozoic strata of Sweden and the Island of Bornhelm, while beds of almost pure glauconite are described from the Silurian of Esthland. Near St. Petersburg the so-called "Ungilitensand" of Lower Silurian age is rich in greensand. In Bohemia, also, glauconite has been found in a coarse-grained sandstone of Barrande's Étage D (Lower Silurian). It has also been reported from the Carboniferous elsewhere in Europe.

In Mesozoic formations the occurrence of glauconite is much more frequent than in the Palæozoic. The Triassic affords numerous deposits in Germany, viz., in the Muschelkalk of Wurtemberg, Bavaria, and at other points to the north in central Germany, and in the Keuper of Swabia and Franconia. The Jurassic has a still larger development of greensand. It is found in the Lias of Bavaria and in the middle and upper Jurassic of Russia, Swabia, Franconia and England.

The greatest deposits of glauconite in the Mesozoic occur, however, in the Cretaceous. Among these are the New Jersey strata, the most extensive and characteristic of greensand accumulations. Outside of New Jersey glauconite has been recognized in other portions of the Cretaceous belt of the South Atlantic and Gulf States, while in Europe it is prominently represented in the Neocomian, Gault and Cenomanian of Germany, France and England. The glauconitic deposits of the English Neocomian and Cenomanian are so prominent a feature that they were early given the names of the Lower and Upper Greensand respectively.

In the Cenozoic, the Tertiary in many portions of the world affords greensand deposits. The Eocene of Maryland and Virginia is largely composed of greensand beds, while glauconite has been observed less numerously at the same horizon in North Carolina, South Carolina and Alabama. The Jackson group of the latter State is particularly rich in greensand.

In the European Eocene, glauconite has been found in considerable quantities in the Thanet sand and Barton clay of England and the Sables de Bracheux and Calcaire Grossier of France. The Nummulitic sandstone of the Alps is characterized by an extensive development of

greensand throughout the area of its occurrence, and the locality of Traunstein, in Bavaria, is especially renowned through the investigations of Ehrenberg. The later Tertiary strata of north and south Germany, Austria, Italy and Belgium likewise afford greater or less amounts of glauconite, so that the Tertiary is hardly second to the Cretaceous in the importance of its greensand deposits.

This brief review of the occurrence of greensand is sufficient to show how wide is its distribution in the geological formations of the earth's crust. Although nowhere else so splendidly exhibited as in New Jersey, it is nevertheless found at all the more prominent horizons and frequently in sufficient amounts to characterize the strata.

THE NEW JERSEY DEPOSITS.

The preliminary examination of the materials collected from the greensand deposits of New Jersey warrants the conclusion that they present characters closely related to the materials from modern seas. We find an extensive series of strata in which at certain horizons thick layers of almost pure greensand are found, surpassing in extent similar deposits in other portions of the earth's crust and in purity, those forming to-day on the sea-bottom.

Although no systematic examination of the deposits has yet been made with the microscope by means of thin sections, such as were employed in the investigation of the Challenger material, still shells and casts of foraminifera have been frequently observed, while other calcareous organisms are very numerous. The associated materials were also largely derived from the crystalline rocks of the Piedmont Plateau, in which quartz, feldspar, mica, hornblende, augite, magnetite and other continental minerals are common constituents, so that the elements necessary for the production of glauconite were present and in a manner most favorable. It seems probable that conditions suitable for the formation of glauconite in late Cretaceous time must have existed from fifteen to twenty-five miles off the coast, and if we accept the theory of Davis, hitherto presented, the present situation of the greensands would correspond very well with the supposed position of that Cretaceous coast. The latter, however, must have been constantly changing during the period. The frequent variations in the character of the deposits, even after greensand deposition had commenced, together with the wide areal distribution of the greensand

itself, as shown by deep borings in the eastern portions of the State, would seem to point to this conclusion. At times the admixture of land-derived materials was so great that the formation of greensand very nearly ceased, while at other times the production went on so continuously that the entire bed, many feet in thickness, was composed almost entirely of glauconite. The Lower, Middle and Upper Marl Beds present the best instances in the New Jersey formations of continued conditions favorable to the production of glauconite, since in each case extensive deposits of greensand, many feet in thickness, were formed. The Clay Marl and Red Sand formations also contain greensand, in the former as interstratified layers, in the latter as scattered grains throughout the deposit, so that the entire Cretaceous series above the Raritan formation is characterized by the presence of glauconite in greater or less amounts.

The oxidation which takes place in the greensands, with the consequent production of red and yellow sands, is a marked feature in the New Jersey deposits. In all instances the thinned-out edges of the greensand layers become altered, although oftentimes the oxidation only extends a slight distance below the surface of the individual grains of glauconite, so that when crushed the deep green color is immediately seen. At other times the oxidation is more complete, and the original character of the deposit is more difficult to ascertain, but even here it is rare for all trace of the glauconite to disappear. The Red Sand affords the most striking instance among the New Jersey deposits of extensive alteration. Although much more quartzose than the marl beds which lie above and below it, the Red Sand, nevertheless, possessed originally a marked percentage of glauconite, which has become partly or entirely oxidized, giving the deep red color so characteristic of the deposit. The loose, porous character of the strata has allowed this change to go on everywhere, and not merely, as in the case of the marl beds, on their thinned-out and exposed edges. Well-borings show the existence of the Red Sand far beneath the surface with its highly-oxidized and quartzose greensand.

Altogether, the greensand beds of New Jersey are among the most striking deposits in the State. It is important that they should be fully examined in the light of modern research, and it is purposed in the continuation of the investigations of the greensand area of the State to give much attention to this subject. The cause of the accumulation of the extensive greensand deposits of New Jersey has long

been a question which has elicited much interest, not only on account of the scientific problems involved, but because the agricultural prosperity of the Marl Belt has brought the inquiry to the attention of every resident of the region. The investigations of the deposits forming in existing seas seem to have afforded the means for the final solution of this question.

SUMMARY.

In reviewing the statements of the preceding pages, it will be seen that glauconite is widely distributed throughout deposits of past geological ages, as well as in those forming upon the floor of existing seas. The area of its formation in sufficiently large quantities to constitute a green sand or mud is limited to exposed coasts and to depths just beyond the action of waves and currents. It is never found along portions of the coast where the accumulation of sediment is rapid, nor does it extend to great depths. The conditions most favorable to its formation are found along the higher portions of the continental slope, where not interfered with by the entrance of large streams bearing sediment from the land.

The glauconite occurs as green grains, which frequently show themselves to be casts of foraminifera and other calcareous organisms. The minute grains, which seldom exceed 1 mm. in diameter, occasionally become agglomerated into nodules of much larger size, in which the cementing substance is generally phosphatic.

A thin section of glauconite beneath the microscope presents no special structure, being entirely homogeneous. Between crossed nicols it shows aggregate polarization, while the individual particles have very indefinite contours.

Glauconite is always associated with those minerals common to the rocks of the land, such as quartz, feldspar, mica, hornblende, augite and magnetite, and with fragments of the rocks themselves, among which gneiss, mica-schist and granite are common types. The shells of foraminifera and other calcareous organisms are generally found, and in fact are essential to the formation of glauconite. The chambers become filled with the muddy sediment, and then, according to Murray and Renard, "if we admit that the organic matter inclosed in the shell, and in the mud itself, transforms the iron in the mud into sulphide, which may be oxidized into hydrate, sulphur being at the same time liberated, this sulphur would become oxidized into sulphuric acid,

which would decompose the fine clay, setting free colloid silica, alumina being removed in solution; thus we have colloid silica and hydrated oxide of iron in a state most suitable for their combination." The potash which is necessary to complete the composition of glauconite may be derived from the decomposition of the fragments of crystalline rocks or their common constituents, orthoclase and white mica.

The greensand deposits of New Jersey are generally considered to have been formed under conditions similar to those which obtain for the production of glauconite in existing oceans. They afford three well-marked greensand horizons, viz., the Lower, Middle and Upper Marl Beds, together with two in which the greensand is sparsely represented, viz., the Clay Marl and Red Sand formations. The oxidation of the glauconite grains with the production of red and yellow sands is seen in the case of the marl beds to be chiefly confined to their exposed portions, while it has extended everywhere throughout the deposits of the Red Sand formation.

The greensand deposits of New Jersey are among the most striking in the State, and upon both scientific and economic grounds demand fuller investigation.

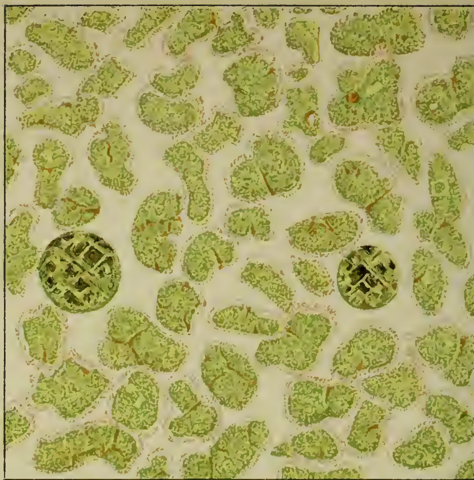
GREENSAND

FROM THE AUSTRALIAN COAST

PLATE IV.

Glauconitic particles that remain after the removal of the carbonate of lime from a deposit off the coast of Australia (magnified 35 diameters). On the removal of the carbonate of lime there is seen to be a very large number of casts of the calcareous organisms. The chambers of the shells are filled, or partially filled, with red, yellow, brown or pale-green casts in various stages of consolidation. When these casts are not opaque, they give aggregate polarization. Besides the casts there are many grains in the deposit similar to those described by mineralogists under the name of glauconite, which in many cases show roughly the form of the foraminifera. Locality: Challenger Expedition Station 164 B; 410 fathoms; South Pacific.

(This plate is reproduced from Challenger Expedition Report on Deep-Sea Deposits, Plate XXIV., Fig. 2.)



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VARIOUS PHASES
IN THE
FORMATION OF GLAUCONITE

PLATE V.

Illustrates various phases assumed by glauconite in existing oceans.

Fig. 1. Glauconite casts and particles from off the coast of Australia as seen between crossed nicols, showing aggregate polarization. Little green and blue points form a very fine mosaic on a brownish-colored ground. Locality: Challenger Expedition Station 164 B; 410 fathoms; South Pacific. (Magnified 50 diameters.)

Fig. 2. Glauconite like particles of a brown-green color. The mammillated surface is quite like a typical glauconitic grain, but this particular grain appears to be an altered rock fragment.

Fig. 3. Particle of a lighter color than the preceding, but having apparently a similar origin.

Fig. 4. Specimen of *Globigerina bulloides* filled with a glauconitic cast.

Fig. 5. Specimen of *Truncatulina refulgens* filled with a glauconitic cast.

Fig. 6. Specimen of *Miliolina seminulum* filled with cast.

(This plate is reproduced from Challenger Expedition Report on Deep-Sea Deposits, Plate XXV., Figs. 1–6.)


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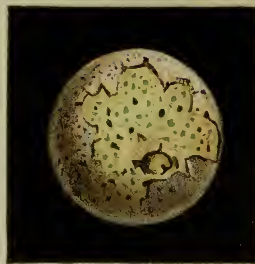
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VARIOUS PHASES
IN THE
FORMATION OF GLAUCONITE

PLATE VI.

Fig. 1. Specimen of *Uvigerina pygmæa* filled with cast.

Figs. 2 and 3. Casts of *Orbulina universa.*

Fig. 4. Cast of *Anomalina coronata.*

Fig. 5. Cast probably formed in the interior of *Orbulina universa.*

Fig. 6. Specimen of *Globigerina pachyderma* filled with cast.

Fig. 7. Cast of *Polystomella arctica.*

Fig. 8. Cast of *Anomalina coronata.*

(This plate is reproduced from Challenger Expedition Report on Deep-Sea Deposits, Plate XXV., Figs. 7–14.)

PART III.

Water-Supply and Water-Power.

BY

C. C. VERMEULE.

WATER-SUPPLY AND WATER-POWER.

BY C. C. VERMEULE.

The work of collecting data for the general report upon the streams of the State has continued through the year. Observations of stream-flow have proceeded on the more important streams and recently some full studies have been made of flood-flows upon the Passaic and elsewhere. It is thought that sufficient data are in hand for the completion of our work, but the collation, arrangement and comparison of this material will still require some time. The attempt to work out a more satisfactory and natural theory of stream-flow than has heretofore existed promises to be successful but involves much careful consideration.

The question of domestic water-supply grows in importance in just the ratio that has been predicted in the past. The most serious problems arise in the populous district of the northeast, near New York.

WATER-SUPPLY OF NORTHERN NEW JERSEY CITIES.

The city of Newark is now drawing its supply from the Pequannock river through the plant installed by the East Jersey Water Company.

There has been a great deal of discussion as to the quantity of water available from the gathering grounds utilized by these works.

Our investigations of rainfall and stream-flow indicate that we can at all times depend on collecting fourteen inches of the rainfall on the Pequannock, provided we have seven inches of storage for all portions of the water-shed. It will not do to merely provide a total storage equal to seven inches of rainfall on the gathering ground, but storage to this amount must be furnished for every portion of the area. The area tributary to the Macopin intake is 63.7 square miles,

and the above figures show that with storage for all portions of the shed equal to seven inches of rain we can collect in the driest year 42,000,000 gallons daily. At present 27.6 square miles of the upper water-shed is tributary to Oak Ridge reservoir, the capacity of which equals 5.32 inches thereon. Clinton reservoir affords storage equal to 20.5 inches rainfall on its 9.9 square miles of water-shed. There is consequently a surplus over the needed amount here. Macopin lake will furnish the needed amount of storage for its own water-shed of two and one-half miles. Forty square miles of the 63.7 square miles are therefore provided with storage, and the remaining 23.7 square miles are practically destitute. During an extremely dry period this 23.7 square miles will furnish an average of only 4,600,000 gallons daily, and by careful management the water-shed as now improved may be depended upon for about 30,000,000 gallons daily in the driest year. The addition of 900,000,000 gallons storage above Oak Ridge reservoir, sites for which are available, and 5,765,000,000 gallons on the lower water-shed, which will be more difficult to procure, will afford a continuous supply of 42,000,000 gallons daily.

Newark is fortunate to be in the full enjoyment of a pure supply of water, such as this unquestionably is under present conditions. The fact that all of the visible supply above the intake will be needed within a reasonable period is nevertheless apparent.

Jersey City has agitated the question of a pure supply vigorously during the year, and it seems fitting that the Survey should again set forth the sources now available for supplying northern New Jersey towns with water. Briefly, these are the following water-sheds:

Hackensack above New Milford.—Elevation at outlet, 4 feet. Supplying capacity, 76,590,000 gallons daily, used by Hackensack Water Co., Re-organized, to supply Hoboken, Hackensack, &c.

Saddle River above Paramus.—Elevation at outlet, 90 feet. Supplying capacity, 14,000,000 gallons daily. Not utilized.

Ramapo above Pompton.—Elevation, 202 feet. Supplying capacity, 107,000,000 gallons daily. Not utilized.

Wanaque above Pompton.—Elevation, 200 feet. Supplying capacity, 73,000,000 gallons daily. Of the 109 square miles of water-shed, 28

square miles are tributary to Greenwood lake, a storage reservoir of Morris canal, the waters of which have to flow almost the whole course of the stream. The rights of the canal company on this stream are important.

Pequannock above Pompton.—Elevation of outlet, 220 feet. Supplying capacity, 56,000,000 gallons daily. Utilized by East Jersey Water Company for Newark supply.

Rockaway above Boonton.—Elevation, 480 feet. Supplying capacity, 78,000,000 gallons daily. Not utilized. The Morris canal draws its supply from Lake Hopatcong and has claimed that it diverts no waters from the Rockaway permanently.

The above are the only practicable sources of supply north of the Raritan water-shed which are sufficient for towns of over twenty thousand inhabitants. Of these, only Saddle river, Ramapo, Wanaque and Rockaway rivers are available for new systems of supply of any magnitude. The aggregate supplying capacity of these four streams is 277,000,000 gallons daily. These are the sources to which our large cities must go in order to acquire ample, independent supplies.

The importance of a proper development of these sources has frequently been pointed out, and it grows in the eyes of the close observer with every census and with the accumulation of data as to our water-sheds. Taking the counties of Hudson, Essex and Union, with Passaic, north, to and including Paterson and Bergen northward to Hackensack, we have a population practically all dependent upon public water-supply systems. The growth of this population is shown by the following table:

CITY POPULATION OF NORTHERN NEW JERSEY.

Year.	Population.	Increase, per cent.
1840	72,404	...
1850	116,932	62
1860	224,617	92
1870	370,957	65
1880	516,192	39
1890	726,442	41

The increase for the last two decades is about 40 per cent. The consumption of water in the larger cities is above 100 gallons per capita daily, and the tendency is to increase. Taking this as the rate, 72,000,000 gallons would be required daily, but the actual consumption may be estimated at 60,000,000 gallons in 1890. Increasing at the rate of 40 per cent., this would become as follows: 1900, 84,-000,000; 1910, 117,600,000; 1920, 164,400,000; 1930, 230,400-,000; 1940, 322,600,000; 1950, 451,700,000 gallons daily.

Now, the total supply, above indicated, of potable waters reasonably accessible to this district is 409,000,000 gallons daily, and by our estimates this will all be required in about fifty years, which is not a long time for a State to look forward. The necessity of wise and judicious development of these water-sheds for the benefit of all of this populous district, rather than their segregation to the uses of a few powerful communities, is what these figures seem to teach.

The entire metropolitan population, including the above and the counties of New York, Kings and Richmond, with Long Island City and Newtown, in Queens county, State of New York, aggregated 3,180,038 in 1890, and the average increase for three decades has been 32.2 per cent. Estimating an increase of 30 per cent. per decade, it will reach 15,349,000 by 1950, and will require, at 100 gallons per capita, 2,300 square miles of water-sheds to supply it. It can readily be seen that all potable waters will eventually become of great value, and that the question can only be successfully dealt with as a whole, comprehensively.

SOUTHERN NEW JERSEY WATER-SUPPLY.

There are certain peculiarities of southern New Jersey water-sheds which are favorable to purity of their waters. Large areas are very sparsely populated and almost entirely in forest, particularly on the Great Egg Harbor, Mullica and upper Rancocas, Toms river, the Metedeconk and some of the smaller coast streams. The nature of the soil is to permit very free percolation of the water which falls upon it in rain. No matter how heavy the downpour, it is a rare sight to see any water running over the surface to the stream. Sinking at once into the sand it finds its way gradually to the stream bed. Consequently it can carry with it no effete organic matter to pollute the water-courses, as is done by the rush of surface-water over steeper

slopes and less penetrable soils after heavy showers. Another consequence is that muddiness is almost impossible. The existence of malarial diseases is unknown even in the densest and wettest of the southern New Jersey swamps. This fact is one which should command the attention of sanitarians. The fact is indisputable.

The availability of these southern stream-waters for public water-supply cannot be questioned, except for the occasional occurrence of a trace of acidity, which has a corrosive effect upon steam boilers, but which could probably be readily neutralized if necessary. The supplying capacity of some of these streams is large. The elevation is generally too little for gravity supply. The following are some of the more important water-sheds:

Stream.	Daily Supply, Driest Year.
Toms River at village	108,000,000 gallons.
Cedar Creek at village	37,000,000 "
Wading River at Harrisia	102,000,000 "
Mullica River at Batsto	130,000,000 "
Great Egg Harbor, Mays Landing,	144,000,000 "
Maurice River, Millville,	146,000,000 "
Rancocas, South Branch,	112,000,000 "
Rancocas, North Branch,	96,000,000 "

These southern New Jersey streams will be found valuable potable waters when the time comes to utilize them. The popular idea has been that we must go to the hills for pure waters, but there is little doubt that a systematic comparison at all seasons would result favorably to such of these streams as have forested water-sheds at least, if not to all of them.

EXTRACTS FROM GENERAL REPORT.

The following are extracts from the full report on this subject now under preparation. Deductions from collections of observations are modified by each new series obtained, and as gaugings are continually accumulating, these pages are still subject to revision. The object in printing, in fact, is to render this revision more thorough as well as to present the information as early as possible for use:

PHENOMENA OF RAINFALL, EVAPORATION, STREAM-FLOW AND GROUND-STORAGE.

As a preliminary to any intelligent study of the flow of streams, we must consider the causes which give rise to the phenomenon.

The waters of the earth are taken up by the process which we call evaporation and formed into clouds, to be again precipitated to earth in the form of rain or snow. Of the water which falls upon the basin of a stream, a portion is evaporated directly by the sun; another large portion is taken up by plant-growth and mostly transpired in vapor; still another portion, large in winter but very small in summer, finds its way over the surface directly into the stream, forming surface or flood-flows; finally, another part sinks into the ground to replenish the great reservoir from which plants are fed and stream-flows maintained during the periods of slight rainfall, for the rainfall is frequently, for months together, much less than the combined demands of evaporation, plant-growth and stream-flow. These demands are inexorable, and it is the ground-storage which is called upon to supply them when rain fails to do so.

All of these ways of disposing of the rain which falls upon the earth may be classed as either evaporation or stream-flow. Evaporation we make to include direct evaporation from the surface of the earth, or from water surfaces, and also the water taken up by vegetation, most of which is transpired as vapor, but a portion of which is taken permanently into the organisms of the plants. Stream-flow includes the water which passes directly over the surface to the stream, and also that which is temporarily absorbed by the earth to be slowly discharged into the streams. A portion, usually extremely small, passes downward into the earth and appears neither as evaporation nor as stream-flow. It is too small to be considered, and we may for our purposes assume that all of the rain which falls upon a given water-shed and does not go off as stream-flow is evaporated, using the latter word in the broadened sense which we have above described.

It has too often been assumed, in treating of stream-flow, that it is directly proportional to the rainfall. An almost continuous effort has been made to compute the flow of the stream for a given month as a percentage of the rain falling in that month. The fallacy of this method should appear with very little study. Streams will continue to flow for weeks and deliver large quantities of water, even if not a

single drop of rain falls. Plants continue to grow and consume water for weeks after all rain has ceased. In both cases the earth supplies the demand. It is a great reservoir, which is full at the end of a wet season and more or less depleted at the end of a dry season. When depleted, a large part of the rainfall must go to refill it and consequently has no direct influence upon stream-flow.

The only way, therefore, in which we can compute the flow of a stream from the rainfall upon its water-shed is to determine how much will be evaporated, how much can be drawn from ground-storage, and how much will be required at any given time to replenish the ground-water. We must consider these quantities separately.

EVAPORATION.

Without long series of accurate gaugings, such as are very rarely obtainable, it is a very difficult matter to determine what will be the evaporation from a given water-shed under the conditions which actually obtain in nature. We have measurements of evaporation from water-surfaces, but there is very little water-surface exposed on our water-sheds; so we have measurements of the amount taken up by various kinds of vegetation, but our areas are of a mixed character and it is not always possible to apportion them properly among the various crops. The measurements of evaporation from the ground come the nearest to what we need, but few of these have been made with necessary precautions to secure exactly the same conditions which exist in nature. Nevertheless, these observations are very suggestive, and some of the results are here reproduced.

The following tables are copied from Mr. Fanning's valuable treatise on water-supply engineering:

EVAPORATION FROM WATER AT EMDRUP, DENMARK.

Latitude, 55° 41′ N.; Longitude, 12° 34′ E. from Greenwich.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
1849...........	1.1	0.3	1.8	2.5	4.1	5 8	4.7	4.0	2.6	1.1	0.9	0.6	29.5
1850...........	1.1	0.3	1.2	1.7	4.5	5.6	4.8	4.8	2.4	1.6	0.9	0 2	29.1
1851...........	0.5	0.4	0.7	1.7	4.2	4.8	5.7	5.1	2.7	1.5	0.6	0.5	28.4
1852...........	0.7	0.5	0.8	2.4	3.8	4.6	6.4	4.5	2.7	1.7	0.8	0.5	29.4
1853...........	0.5	0.1	0.7	1.0	4.1	6.2	5.1	4.2	2.8	1.1	0.6	0.5	26.9
1854...........	0.5	0.9	0.9	3.2	3.3	4.5	5.2	4.3	2.6	1.2	0.7	0.6	27.9
1855...........	1.0	1.1	0.5	1.2	2.6	4.1	4.7	4.1	2 8	1.4	0.9	0.7	25.1
1856...........	0.5	0.5	1.2	2.1	2.8	4.6	4.3	4.0	2.0	1.9	0.6	0.5	24.0
1857...........	0.7	0.6	0.6	1.4	4.1	6.6	5.9	4.3	3.2	1.4	0.7	0.4	29.9
1858...........	0.4	0.7	1.2	3.1	5.1	6.1	4.9	5.6	2.8	1.6	0.7	0.4	30.6
1859...........	0.3	0.5	0.7	1.9	4.3	5.8	5.3	3.8	1.8	1.0	0.7	0.3	26.4
Mean.........	0.7	0.5	0.9	2.0	3.7	5.4	5.2	4.4	2.6	1.3	0.7	0.5	27.9
Ratio.........	.301	.215	.387	.860	1.592	2.323	2.237	1.892	1.118	.559	.301	.215	......

MEAN EVAPORATION FROM SHORT GRASS, 1852 TO 1859, INCLUSIVE.

Mean.........	0.7	0.8	1.2	2.6	4.1	5.5	5.2	4.7	2.8	1.3	0.7	0.5	30.1

MEAN EVAPORATION FROM LONG GRASS, 1849 TO 1856, INCLUSIVE.

Mean.........	0.9	0.6	1.4	2.6	4.7	6.7	9.3	7.9	5.2	2.9	1.3	0.5	44.0

MEAN RAINFALL AT SAME STATION, 1848 TO 1859, INCLUSIVE.

Mean.........	1.5	1.7	1.0	1.6	1.5	2.2	2.4	2.4	2.0	2.3	1.8	1.5	21.9

EVAPORATION FROM EARTH.

MEAN EVAPORATION FROM EARTH, AT BOLTON LE MOORS,* LANCASHIRE, ENGLAND, 1844 TO 1853, INCLUSIVE.

Latitude, 53° 30′ N.; Height above sea, 320 feet.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
Mean........	0.64	0.95	1.59	2.59	4.38	3.84	4.02	3.06	2.02	1.28	0.81	0.47	25.65
Ratio........	.299	.444	.739	1.212	2.049	1.796	1.887	1.431	.945	.599	.379	.220	....

* Beardmore's Hydrology, page 325.

MEAN RAINFALL AT SAME STATION, 1844 TO 1853, INCLUSIVE.

Mean	4.63	4.03	2.25	2.22	2.23	4.07	4.32	4.77	3.79	5.07	4.64	3.94	45.96

MEAN EVAPORATION FROM EARTH, AT WHITEHAVEN, CUMBERLAND, ENGLAND, 1844 TO 1853, INCLUSIVE.

Latitude, 54° 30′ N.; Height above sea, 90 feet.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
Mean......	0.95	1.01	1.77	2.71	4.11	4.25	4.13	3.29	2.96	1.76	1.25	1.02	29.21
Ratio......	.390	.415	.727	1.113	1.689	1 746	1.697	1.352	1.216	.723	.513	.419	....

MEAN RAINFALL AT SAME STATION, 1844 TO 1853.

Mean......	5.1	3.4	2.5	2.2	1.9	3.1	4.3	4.3	3.1	5.3	4.5	3.8	43.5

The next table is a very instructive one, furnished by Desmond Fitz Gerald, C.E., in a paper on "Rainfall, Flow of Streams and Storage" (Transactions of the American Society of Civil Engineers, Vol. XVII., No. 3). The table is partially made up from a diagram, so that to a certain extent the figures are averages, but only when the observations were so near to a mean as to warrant such a course:

Evaporation from Water-Surface at Boston, Mass., in Inches—Sixteen Years.

	1876.	1877.	1878.	1879.	1880.	1875–1890 and 1881–1884.	1885.	1886.	1887.	1888.	1889.	1875–1890. Total.	1875–1890. Mean.
January	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	15.36	0.96
February	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	16.80	1.05
March	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	27.20	1.70
April	2.98	2.98	2.98	2.98	2.98	2.98	2.98	3.12	3.07	2.78	2.84	47.57	2.97
May	4.45	4.05	4.14	5.89	5 22	4.45	3.77	4.45	4.83	3.35	4.57	71.42	4.46
June	5.44	5.68	5.26	5.32	6.46	5.55	7.01	5.25	5.05	5.98	3.94	88.69	5.54
July	7.50	4.82	6.04	6.41	5.82	5.98	7.09	5.59	5.96	5.57	5.04	95.72	5.98
August	6.21	4.40	4.33	5.23	5.34	5.50	7.41	5.80	6.20	5.81	4.25	87.98	5.50
September	3.48	4.08	4.04	3.80	4.04	4.20	5.13	4.55	4.57	3.91	3.08	65.88	4.12
October	3.12	2.51	3.52	2.99	2.79	3.11	2.79	4.13	3.61	3.27	3.13	50.52	3.46
November	0.66	2.23	2.23	2.23	2.60	2.23	2.23	2.69	3.00	2.71	1.98	35.94	2.25
December	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	24.16	1.51
Total	39.06	35.97	37.76	40.07	40.47	39.22	43.63	40.80	41.51	38.60	34 05	627.24	39.20

The small range of the evaporation from water in the tables is suggestive. It seems to approximate to a constant in each month. Of the tables of evaporation from earth, that at Whitehaven seems to be the better adapted to our climate. It is more valuable for the dry months than for winter.

The following is Risler's table of daily consumption of water for different crops, quoted in an article on irrigation by W. Tweeddale, C.E. (Kansas State Board of Agriculture Report, December 31st, 1889):

	Inches.
Lucern grass	from 0.134 to 0.267
Meadow grass	from 0.122 to 0.287
Oats	from 0.140 to 0.193
Indian corn	from 0.110 to 1.570
Clover	from 0.140 to ......
Vineyard	from 0 035 to 0.031
Wheat	from 0.106 to 0.110
Rye	from 0.091 to ......
Potatoes	from 0.038 to 0.055
Oak trees	from 0.038 to 0.030
Fir trees	from 0.020 to 0.043

From these and other observations, Mr. Tweeddale concludes that from seed-time to harvest cereals will take up fifteen inches of water and grasses thirty-seven inches. These conclusions agree with practice in irrigation, and show plainly that the demands of plant-growth cannot be ignored in tracing the disappearance of rain. The figures also explain the low summer flow of streams flowing from a highly-cultivated water-shed. They do not necessarily explain the effect of forests in regulating flow, since many water-sheds, although cleared of trees, are not put under cultivation but still show some change in flow. The action of forests is probably largely to retard surface-flow by means of irregular surfaces, caused by roots, fallen timber, absorbent mosses and leaf accumulation, thus holding the water until it can be taken into the ground. This is not mere theory; it is based on observations made during many days spent in the forest, and is believed to almost if not fully account for the better-sustained flow of forest streams and their lighter flood-flows.

Evidently, if all of our water-shed should be covered with grain and heavy grasses, there would be very little water left for the sustenance of stream-flow during the summer. Fortunately, a much smaller proportion is so covered than is usually supposed, even in

agricultural sections. Somerset county is a highly-cultivated section of the red sandstone plain. I have made an estimate of the proportion of the total area given to various crops, based on census figures, and the proportion of wooded area has been measured. Of the total area, 13 per cent. is wooded in large tracts, and 7 per cent. has been added for scattering timber, the remainder being devoted to general farming.

PERCENTAGE OF AREAS DEVOTED TO VARIOUS CROPS IN SOMERSET COUNTY, WITH QUANTITY OF WATER REQUIRED FOR EACH.

CROP.	Per cent. of whole area.	WATER REQUIRED IN ONE GROWING-MONTH. In inches on crop area.	In inches on whole area.
Forest (oak and chestnut)	20	1.2	0.24
Wheat, rye, oats, &c	20	3.5	0.70
Indian corn	11	4.5	0.49
Potatoes and other root crops	5	1.2	0.06
Long grasses	17	6.0	1.02
Short grasses	15	5.0	0.75
Orchards, &c	5	3.0	0.15
Fallow lands and miscellaneous	7	4.0	0.28
Total	100	....	3.69

This gives a fair idea of the allowance which must be made for vegetation, although it is only a rough approximation. To this must be added something for extra evaporation from crop areas. This demand for 3.7 inches of water per month may be considered practically a constant one for the growing-months. It is, to a large degree, independent of the rainfall, and, in fact, a large part of the evaporation is also independent of rainfall.

Somerset county has been selected as a type of the larger part of our red sandstone plain, viz., that part lying southwest of the glacial moraine which passes through Morristown, Plainfield and Perth Amboy.

As a type of our Highland and Kittatinny valley region, Sussex county may be taken in the same way.

PERCENTAGE OF AREA DEVOTED TO VARIOUS CROPS IN SUSSEX COUNTY, AND QUANTITY OF WATER REQUIRED FOR EACH.

CROP.	Per cent. of whole area.	WATER REQUIRED IN ONE GROWING-MONTH.	
		In inches on crop area.	In inches on whole area.
Forest (oak and chestnut)	50	1.2	0 60
Water	2	5.0	0.10
Indian corn	5	4.5	0.22
Other cereals	9	3.5	0.32
Long grasses	3	6.0	0.18
Short grasses	24	5.0	1.20
Potatoes and other root crops	1	1.2	0.01
Fallow land	6	4.0	0.24
Total	100	....	2.87

The southern New Jersey agricultural counties will not differ very materially from Somerset county, while the piny region will only call for about one inch of water per month for plant growth. The evaporation there is large, however; much greater than in northern New Jersey, as we shall see when the study of the streams is taken up.

It would be difficult to determine just how much evaporation will take place in addition to the water demanded by plant growth. It is hardly probable that it is nearly so large as the evaporation from bare ground, and, for the heavier absorbents and closer-growing crops, such as long grasses and clover, there is probably no additional evaporation. The only practical way to fix the evaporation from different types of topography and country, under various stages of cultivation, is by means of a series of accurate gaugings of typical streams and synchronous measurements of rainfall. The above figures are not here intended to be given as actual measurements of the evaporation, as in no case do they apply to the actual conditions obtaining in practice. They are of value only as indicative of what may be expected and of the distribution of evaporation by months. For actual values we prefer to look to stream gaugings and learn what we can from these. If we take a series of monthly rainfall and monthly streamflow, such as we have given elsewhere in full, and carefully analyze

them, we can determine what the evaporation will be for a given period. It would at first sight appear that it will be simply the difference between the rainfall and the stream-flow, but this error we must carefully guard against. It neglects entirely the water which may have been stored in or drawn from the earth. If the ground contains the same amount of water at the beginning and at the end of the period in question, then evaporation plus stream-flow equals the rainfall. If the ground is full at the beginning but depleted at the end, then evaporation plus stream-flow equals rain plus amount drawn from storage in the ground. If the period begins with low ground-water and ends with full, then evaporation plus stream-flow plus amount stored in ground equals rainfall. I have in some cases found the ground capable of supplying the equivalent of over five inches of rainfall to the stream. The neglect of this important factor has often led to great confusion and false deductions. Experience enables one to soon detect from a table of gaugings and contemporaneous rainfall when ground-water is full and when depleted on a water-shed. In deducing evaporation from gaugings I have taken periods beginning and ending with full ground-water.

Another matter which I may call attention to here is the evil which results from dividing years of gauging at January 1st. Such a division introduces needlessly the uncertainties due to rainfall carried over in the form of snow or ice from one year to the next, and so appearing in the next year's flow. I find the best date at which to begin a year for these purposes is December 1st, as usually there is no snow or ice and ground-water is full.

EVAPORATION DEDUCED FROM GAUGINGS.

For the preliminary studies of this subject I have used a thirteen-year series of gaugings upon the Croton river and a sixteen-year series upon the Sudbury. I consider these series the best for the purpose. They have the advantage of being upon comparatively small streams, which respond promptly enough to rainfall to enable us to separate the rainfall and flow quite accurately into months. Still they are large enough to cover a considerable extent of territory and give a fair average result for the class of topography for which they are good types. I give the tables of rainfall and flow in full elsewhere. The figures below are averages from carefully-selected periods :

YEARLY RAINFALL, FLOW AND EVAPORATION—INCHES ON THE WATER-SHED.

Croton Water-Shed, Area 353.1 Square Miles.

Rain.	Flow.	Evaporation.
39.67	18.15	21.52
40.40	19.36	21.04
43.77	21.26	22.51
45.82	22.43	23.39
49.83	23.11	26.72

Sudbury Water-Shed, Area 78 Square Miles.

Rain.	Flow.	Evaporation.
30.86	11.41	19.45
40.40	18.44	21.96
44.68	22.53	22.15
45.95	24.33	21.62
47.31	25.35	21.96
51.30	26.99	24.31

The years here used are generally from November 1st. It is noticeable in the case of the Croton that there is an increase of evaporation with increased rainfall above 40 inches, but so far no decrease has been observed with decreased rainfall. We have said that the demands of plant growth are inexorable. They must be met. Apparently the same is true of direct evaporation, as both these series show little decrease below 40 inches rainfall. Indeed, a single year on the Sudbury indicates 26 inches evaporation with only 38.18 inches rainfall. This I regard as a somewhat doubtful exception, however. The other fact of no perceptible decrease of evaporation is apparently well established by these gaugings. The increase of evaporation with larger rainfalls than 40 inches upon the Croton is explainable by the supposition that such larger rainfalls give rise to large evaporation from surface pools or overflowed swamps. It appears that on the Sudbury the evaporation remains constant up to 47 inches, indicating a greater absorptive power for the water-shed perhaps. When evaporation begins to increase upon these water-sheds, it is at about the rate of one-half the surplus rainfall. Thus on the Croton we may take the evaporation for 40 inches of rain to be 22 inches. Then if we add one-fourth the excess of rain over 40 inches to this evaporation, we have the following :

COMPUTED ANNUAL EVAPORATION ON CROTON WATER-SHED—INCHES.

$$\text{Evaporation} = 21.3 + \frac{\text{Rain} - 40}{2}$$

Rain.	Evaporation.
40.00	22.00
42.00	22.50
44.00	23.00
46.00	23.50
48.00	24.00
50.00	24.50

So on the Sudbury there are evidences of a similar increase above 47 inches of rainfall annually. The Whitehaven observations previously given show an evaporation from earth of 29.21 inches for 43.5 inches of rain; those at Bolton le Moors give rain 45.76, evaporation 25.65, both results being higher than we find above for similar rainfalls, which we may expect from the more open winters at those places. Let us now examine these gaugings for shorter periods:

JUNE TO NOVEMBER—CROTON WATER-SHED.

Rain.	Flow.	Evaporation.
17.25	2.54	14.71
20.86	3.76	17.10
22.28	4.81	17.47
23.94	4.81	19.13
25.71	7.12	18.59
27.30	8.95	18 35

Here also we notice an increase of both evaporation and flow for increasing rainfall, and if we take the normal for 20 inches of rainfall to be 17 inches evaporation, and add to this 25 per cent. of the excess of rain, we have the following:

COMPUTED EVAPORATION—JUNE TO NOVEMBER, CROTON WATER-SHED.

Rain.	Evaporation.
20.0	17.0
22.0	17.5
24.0	18.0
26.0	18.5
28.0	19.0
30.0	19.5

These results also seem to range well with the observed quantities. It may seem, at first sight, strange that we use only 25 per cent. of

excess in the summer months and 50 per cent. for the whole year, but it should be remembered that this percentage represents evaporation from water on the surface in pools, &c., and there is less water so standing during this season, as the ground rapidly absorbs the rain. The constant evaporation for 20 inches of rain for these six months is 17 inches, against 21.3 inches for 40 inches of rain during the whole year. The constant part of the evaporation is much greater, the variable part only being less. It is noticeable that for the smaller rainfall shown, evaporation decreases nearly as fast as the rainfall.

CROTON WATER-SHED, DECEMBER TO MAY.

Rainfall.	Flow.	Loss.	One-fourth Rainfall.
15.74	11.81	3.93	3.92
19.72	14.52	5.20	4.93
21.70	16.07	5.64	5.42
25.18	19.03	6.15	6.29

These figures are averages from the records of flow, excepting the last column, which is added in order to show how closely the observed evaporation for this period agrees with one-fourth of the rainfall.

From June to November, with 20 inches of rainfall, we have 17 inches of evaporation; and from December to May, with 20 inches of rainfall, we have 5 inches evaporation, or with 40 inches annual rain, 22 inches evaporation. We have thus divided the evaporation into two periods of six months each. By closer analysis I find that the 17 inches evaporation for the six summer and autumn months is divided into 11.5 inches for June, July and August and 5.5 inches for September, October and November. A study of the distribution of evaporation by months at White Haven, Bolton le Moors and Boston shows that we may divide these quantities by months as below. For the winter months we have seen that evaporation is proportional to the rainfall for the whole period. It is not so important, as we shall see later, to subdivide this winter and spring evaporation by months, excepting for the month of May. It is fair to assume, however, that this evaporation is distributed as shown in Mr. Fitz Gerald's table of evaporation at Boston, from water surface, which has been given heretofore. I have carefully checked the figures for May thus obtained and find they agree closely with the average results of gaugings. I am, therefore, able to conclude that the monthly evaporation in inches for 40 inches rainfall on the Croton

water-shed closely approximates the following: December, 0 60; January, 0.40; February, 0.40; March, 0.70; April, 1.20; May, 1.70; June, 3.75; July, 4.00; August, 3.75; September, 2.75; October, 1.75; November, 1.00—Year, 22.0 inches. These values are close approximations to the truth for the Croton water-shed, as during these studies they have been checked in many ways and always verified. They are in no way inconsistent with, but, on the contrary, harmonize well with the tables of evaporation previously given. June, July and August are pre-eminently the growing months upon this area, and the effects of the demands of vegetation are shown in the heavy evaporation.

JUNE TO NOVEMBER—SUDBURY WATER-SHED.

Rain.	Flow.	Evaporation.
17.39	2.35	15.04
19.23	2.41	16.82
23.90	4.70	19.20
25.78	6.20	19.58
28.49	6.66	21.83
31.00	11.86	19.14

The agreement between this table and the one for the same months on the Croton is remarkably close. We see that for 20 inches rainfall we have the same (17 inches) evaporation, that the evaporation increases rapidly up to 24 inches rainfall and then remains constant. Our rule adopted in computing evaporation from rain in the Croton gives equally good results here, and, while not exact, is probably as nearly so as we shall require and forms a convenient working rule.

One point is well established by these Sudbury gaugings which was only hinted at upon the Croton, viz., evaporation decreases with less rainfall than 20 inches in summer. Both streams show that for 17.3 inches rain evaporation does not exceed 15.0 inches, showing thus far that evaporation is decreased 75 per cent. of the decrease of rainfall below 20 inches. Reducing these conclusions to the form of equations, we have for the summer and autumn evaporation on the Sudbury and Croton water-sheds: When rain exceeds 20 inches, evaporation $= 17 + \frac{1}{4}$ (rain — 20); when rain is less than 20 inches, evaporation $= 17 - \frac{3}{4}$ (20 — rain). The evaporation by months is the same on the Sudbury that we found for the Croton.

DECEMBER TO MAY, SUDBURY WATER-SHED.

Rain.	Flow.	Evaporation.	One-fourth of Rainfall.
16.61	12.01	4.60	4.15
18.89	14.34	4.55	4.72
21.12	18.00	3.12	5.28
24.22	19.49	4.73	6.05
25.85	19.57	6.28	6.46
27.25	19.99	7.26	6.81

Here as with the Croton we find a tendency toward percentages of rain and evaporation approximates to one-fourth of the rainfall. Or assuming evaporation for 20 inches rainfall to be 5 inches, we may, for any excess of rain, add one-fourth such excess to this evaporation, or for any deficiency subtract one-fourth such deficiency to find the winter evaporation for a given rainfall.

This discussion of the subject of evaporation is necessary to our purpose, but the method which I shall adopt does not require absolute accuracy in determining evaporation. It needs only to be computed closely enough to enable us to detect the beginning and end of a period of depleted ground-water. This enables us to apply correctly our constants of flow, such as I have used in previous reports. These constants of flow, representing the yield from ground-storage independent of rainfall, are our chief reliance for accuracy in computing flow during very dry periods.

The manner in which these constants of flow are determined has been illustrated in my report for 1890. I can best elucidate the method of applying the constants of evaporation and of stream-flow by an actual example. I take the Hackensack river as representative of a type of streams not heretofore dealt with.

FLOW OF THE HACKENSACK RIVER.

CHARACTER OF WATER-SHED.

The water-shed of the Hackensack above New Milford embraces an area of 114.8 square miles, 50.7 in New Jersey and 64.1 in New York. About 60 per cent. of the area is forested, the remainder being under cultivation. The underlying rock is red sandstone, but the whole is quite heavily covered with glacial drift, sand and gravels. The drift covering is especially heavy in the flatter portions of the valley near the streams.

There are several mill-ponds, some quite large, and also quite an area of swamp bordering the streams. These act to regulate the flow somewhat and carry over a considerable flow from wet periods into subsequent months.

The record of rainfall at New Milford I find by comparison with neighboring stations to indicate a lighter rainfall than the average. I do not believe it gives a fair indication of the average for the water-shed, as precipitation on the higher portions is probably heavier. I have, therefore, combined with it a record for Tenafly, on the eastern part of the water-shed, and Newark, which I find fairly represents the fall on the area between the valley of the Hackensack and the high land west. I give in the table the full record for each of these places and also the average which I have used to represent the rainfall on the Hackensack water-shed in the table of rain and river-flow. In this latter table I have reduced the flow to inches upon the water-shed:

RAINFALL TABLES.

Month.	Newark.	Tenafly.	New Milford.	Average.
1890.				
November	0.80	0.76	0.64	0.77
December	4.03	3.38	3.24	3.55
1891.				
January	8.71	7.38	6.86	7.65
February	4.83	4.54	3.57	4.31
March	4.61	3.69	4.55	4.28
April	2.11	2.28	2.23	2.21
May	2.95	2.90	2.41	2.75
June	2.02	2.19	1.65	1.95
July	6.73	3 03	2.47	4.08
August	4.61	3.04	2.96	3.54
September	2.53	2.40	2.34	2.42
October	2.54	2.40	2.15	2.36
Year	46.47	37.99	35.07	39.87
1891.				
November	2.44	2.88	2.95	2.76
December	4.08	4.90	4.78	4.59
1892.				
January	5.63	5.36	5.03	5 34
February	1.62	1.55	0.96	1.38
March	3.54	3.84	2.25	3.21
April	2.28	1.55	1.59	1.81
May	5.48	4.46	5.04	4.99

FLOW OF HACKENSACK RIVER AT NEW MILFORD.

DRAINAGE AREA, 114.8 SQUARE MILES.

Month.	Rain—Inches.	Flow—Inches.
1890.		
November	0.77	2.03
December	3.55	2.50
1891.		
January	7.65	5.30
February	4.31	5.17
March	4.28	4.33
April	2.21	2.66
May	2.75	1.42
June	1.95	0.87
July	4.08	0.72
August	3.54	0.66
September	2.42	0.80
October	2.36	0.56
Year	39.87	27.02
1891.		
November	2.76	0.96
December.	4.59	1.49
1892.		
January	5.34	3.52
February	1.38	1.80
March	3.21	2.60
April	1.81	1.70
May	4.99	1.87
April, 1891, to March, 1892	36.59	18.20

ANALYSIS OF GAUGINGS.

The aggregate flow for the year ending October 31st, 1891, is nearly 68 per cent. of rain. This flow is greatly augmented by heavy draughts upon stored ground-water. However, assuming the evaporation to be the same that I have found it to be upon the Croton water-shed for 40 inches annual rain, we find the supply to and draught from the water-shed to have been as follows:

	SUPPLY.	DRAUGHT.	
	Rainfall.	Evaporation.	Flow.
April–May	4.96	2.90	4.08
June–August	9.57	11.50	2.25
September-October	4.78	4.50	1.36
Total	19.31	18.90	7.69

This shows that at no time after April 1st was the supply equal to the draught. The ground-water was kept depleted for all of this period, and all of the flow, excepting what was due to surface-run during heavy rains was drawn from water stored in the ground from the rain of the previous year. The flow was larger by the amount thus drawn than in a normal year beginning and ending with full ground-water.

The long series of deficient months, or those in which the flow was from ground-water, makes this year an admirable one for determining flow from ground-storage. November, 1890, was a month of very light rainfall, evenly distributed, and the flow for that month may be considered to have been wholly from ground-storage. It fixes the amount for the first dry month following full ground-water at 2.00 inches.

For the months beginning with April 1891, I allow 10 per cent. of total rainfall to represent flow over surface to stream. The balance of flow may be taken as the ground-flow of the Hackensack. In this way I have computed the following table in which I have included similar figures for the Croton and for southern New Jersey streams for ready comparison.

DRY-MONTH FLOW FROM GROUND-WATER.

	Hackensack.	Croton.	Southern New Jersey.
First dry month	2.00	0.81	1.30
Second " "	1.15	0.47	1.00
Third " "	0.68	0.38	0.75
Fourth " "	0.45	0.25	0.60
Fifth " "	0.36	0.20	0.45
Sixth " "	0.34	0.16	0.30
Seventh " "	0.33	0.12	0.30
	5.31	2.39	4.70

These figures and an examination of rain and flow subsequently, convince us that 5.31 inches of the flow for the year was drawn from storage, and should be deducted from 27.02 to give the normal flow due to 39.87 inches of rain, giving 21.71 inches flow.

Again we may take the year from April, 1891, to March, 1892, inclusive, to have begun and ended with full ground-water. This year and the above corrected year I here place with similar figures for the Croton, the latter being the average for the three years of nearly equal rainfall.

	Rainfall.	Flow.	Percentage.
Hackensack, November–October......	39.87	21.71	54 5
Hackensack, April–March..............	36.59	18.20	49.7
Croton, average..............................	39.41	19.12	48.5

We have here indicated a strong resemblance between the two streams in annual flow taken in the aggregate, and this warrants the use of the same constants of evaporation for each.

In the distribution of this flow there is a wide divergence, however. The table of dry-month flows shows a ground-flow from the Hackensack much larger than anything shown by the Croton. We must look to the sandy water-sheds of southern New Jersey for anything like a parallel. The heavy first and second month flow here is attributable to swamp-storage and to the ready delivery of the higher ground-water from the thick beds of drift-gravels lying upon the area. The delivery is a little more rapid than from southern New Jersey streams, and consequently falls a little below those streams at the third to fifth month. In the later months it is apparently fully as well sustained. It is noticeable, also, that the aggregate available ground-water is greater than from the southern streams, owing to the readier outlet afforded by the slopes of the water-shed.

Taking the year 1880, which was an extremely dry year upon the Croton, and using the constants of flow which we have determined, we may estimate the probable flow of the Hackensack to have been as follows:

Month.	Ra nfall.	Evaporation.	Flow.	Ground-water.
December to April...	19.68	......	11.80	Full.
May	1.17	1.70	2.12	Falling.
June.......................	1.28	3.75	1.28	"
July	5.65	4.00	1.24	"
August....................	3.60	3.75	0.81	"
September..............	2.69	2.75	0.63	"

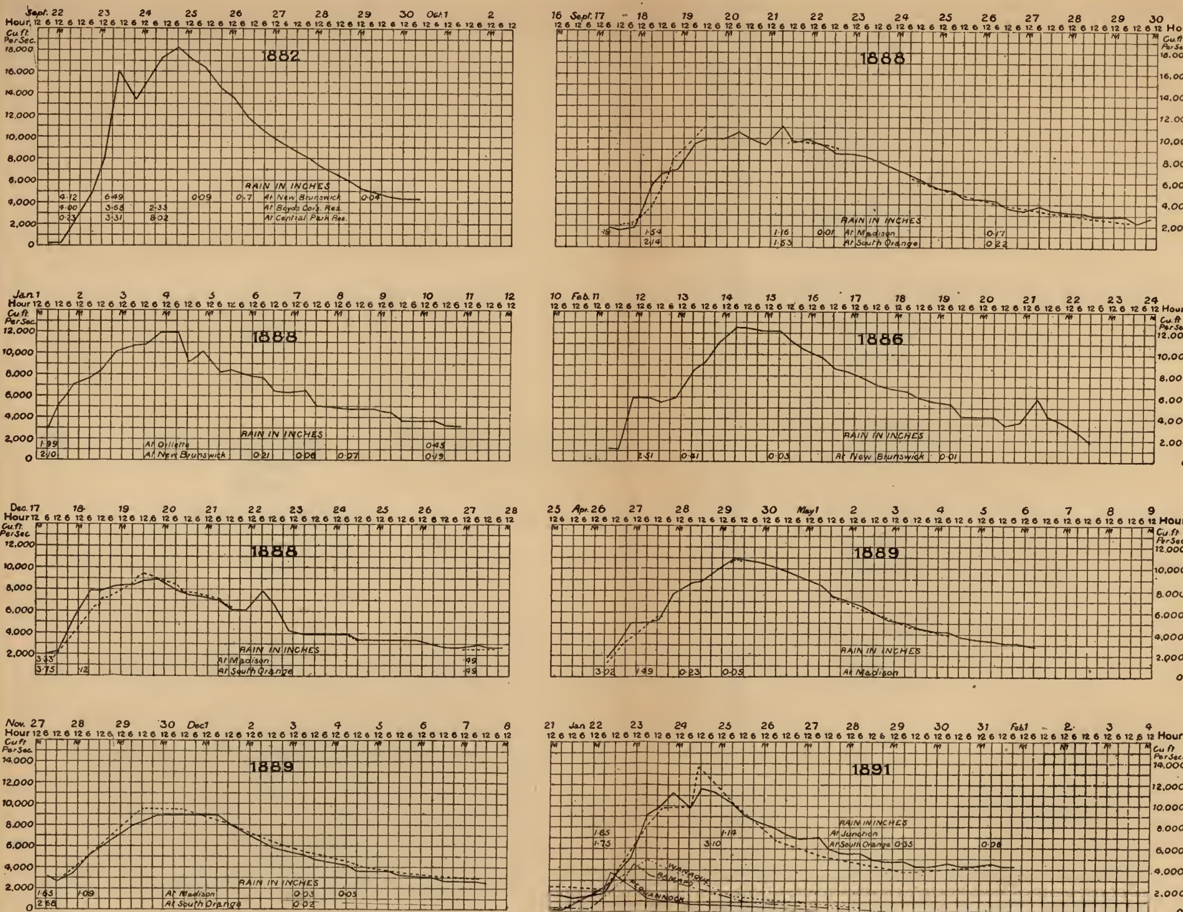
Month.	Rainfall.	Evaporation.	Flow.	Ground-water.
October..................	3.25	1.75	0.64	Rising.
November...	2 97	1.00	0.63	"
December	2.49	0.60	0.55	"
January, 1881..........	4.19	0.40	0.71	Full.

This is allowing 10 per cent. of rainfall for surface flow. This point being to some extent doubtful, it will for the present be conservative to neglect it and take only the flow from ground water previously given, for extreme dry-months. It must be said, however, that the gaugings for 1891, are very strongly indicative of the accuracy of the above estimates. To be entirely safe, therefore, let us assume the flow for such an extreme dry year as 1880 to be as follows:

December to April, 11.80; May, 2.00; June, 1.15; July, 0.68; August, 0.45; September, 0.36; October, 0.34; November, 0.33; December, 0.55; January, 0.71. This gives us a total for 14 months of 18.37 inches, or say 1.25 inches per month. To utilize this we would need storage equivalent to 5 inches upon the water-shed, since 1.25 inches per month from May to January would make 11.25 inches, whereas the flow for this period would be but 6.57 inches. This would indicate the possibility of collecting 15 inches annually upon the Hackensack water-shed. Our records are so suggestive of a total annual yield like that from the Croton, however, and it has been so clearly proven that not more than 14 inches can be collected there, that I consider it safer to take this as the total yield of the Hackensack, and say that with storage equal to 5 inches upon the water-shed we may collect from this water-shed 76,590,000 gallons daily.

FLOOD-FLOWS OF THE PASSAIC.

The accompanying diagram of floods on the Passaic may prove useful. We shall reserve our analysis of these floods for the full report.



DIAGRAMS OF FLOODS ON THE PASSAIC.

FULL LINE - HEIGHT AT DUNDEE.

BROKEN LINE - HEIGHT AT LITTLE FALLS

J.R. Prince Del.

C C Vermeule C E 71 B'way, New York.

PLATE VII.

PART IV.

ARTESIAN WELLS

IN

SOUTHERN NEW JERSEY.

BY

LEWIS WOOLMAN.

ARTESIAN WELLS IN SOUTHERN NEW JERSEY.

BY LEWIS WOOLMAN.

Since the preparation of the last annual report a considerable number of wells have been put down in that portion of the Atlantic seaboard comprised within the comparatively level region of southern New Jersey. From many of these, through the continued courtesy of artesian-well contractors, and also of property-owners, the writer has been furnished with records and specimens. There has also been received information respecting some wells that were bored previous to the year 1892 and that had heretofore escaped notice, and also additional data respecting some wells heretofore reported.

The geological and practical deductions to be drawn from the information obtained will now be stated.

The wells arrange themselves geographically and geologically into two series, first, those upon the ocean side of the State, penetrating Miocene strata, with which may be included geographically some wells that do not reach so low as the Miocene, and second, those upon the Delaware river side entering Cretaceous strata.

I. WELLS IN THE SOUTHERN INTERIOR AND ALONG THE BEACHES.

The wells to be noticed upon the side toward the ocean are located at Waretown, Great Sedge Islands, Port Republic, Harrisia, Atlantic City, Fifields (opposite Longport), Ocean City, Mays Landing, Port Norris, Bivalve, Winslow, and at the following cranberry bogs, viz , at Horner's and at the Atlantic Company's bogs, south of Hammon-

ton; at Rockwood's bog, north of Hammonton; and at Barge's bog, near Pleasant Mills. All of the above enter the Miocene. To them may be added a group of wells, not very deep, near Absecon, which do not reach so low as the Miocene. The details of the wells at each ocality will now be given.

ARTESIAN WELLS AT ATLANTIC CITY.

Consumers' Water Company, three wells, Nos. VI., VII. and VIII.
Knickerbocker Ice Company, one well, also one test-boring.

The wells at Atlantic City will be first noticed, since the section there is the key to the sections elsewhere in Micocene beds. At this place three additional wells, known as Numbers VI., VII. and VIII., have been bored for the Consumers' Water Company. Well No. VI. has a six-inch casing that reaches to the depth of about 710 feet, and draws from the horizon of 700 to 720 feet—that is, from the first water-yielding sand below the diatomaceous bed.

Well No. VII. has a six-inch casing to the depth of 524 feet, with a four-and-one-half inch casing inside this and continued beyond. This well was bored to the depth of 780 feet and finished with a slotted pipe, plugged at the bottom so as to permit the passage of water between the depths of 750 and 780 feet. It flows about 150 gallons per minute.

Well No. VIII. has an eight-inch casing to the depth of 755 feet; the boring, however, was continued beyond this to the depth of 763 feet, at about which depth a good flow of water was obtained.

The water-yielding stratum for the two last-named wells may be called the 760-feet horizon. In both wells the water horizons, previously reported at 525 to 550 feet and at 700 to 720 feet, were met with and passed, as the company were desirous of developing still lower water-producing sands. In proof of the identity of the water-supply of the wells having a depth of 525 to 550 feet, it may be stated that upon stopping the connection with the pumps of all except one and pumping from that one alone, the level of the water was lowered in the others. A similar test was made with the wells having a depth of 700 feet with like results.

In the Annual Report for 1889 it is stated respecting well No. 1, and it is likewise so shown upon the accompanying lithographic section, that the water supplying it came from a depth of about 1,120

feet. At that time this was believed to be the case by those most interested. Soundings recently made show, however, the real depth of the water horizon to be but 960 feet. In explanation it may be stated that the well was drilled to the depth of 1,120 feet, when work was suspended for the winter, during which time a small flow was observed. On the commencement of work the ensuing spring, the inner four-and-one-half-inch casing was withdrawn a short distance, when a copious supply was obtained. The casing was undoubtedly parted, and, quite fortunately, at about 950 to 960 feet, since the sounding revealed the fact that solid clay had filled in the pipe below that depth. This supply has been well maintained ever since, the pumps having drawn upwards of three hundred thousand gallons per twenty-four continuous hours from the well.

A well not yet finished is also being put down at Atlantic City for the Knickerbocker Ice Company. It has attained the depth of about 650 feet, but is not yet completed. It is being bored by P. H. & J. Conlan. The strata penetrated in this well, as also the three wells of the Consumers' Company, just noticed, correspond in all essential particulars with published details of former wells at this locality.

During recent years a number of wells have been put down at Atlantic City to the depths of 55 and 75 feet. The *horizon* reached by these wells will be again referred to in connection with shallow artesian wells near Absecon.

ROBINSON'S TEST-BORING.

In the fall of 1891 a test-boring was made at Atlantic City by J. E. Robinson, of Philadelphia, who kindly furnished some data which have not been given in former reports. The drilling was discontinued in the upper portion of the Miocene strata and only a short distance above the diatomaceous clays, the depth reached being about 350 feet. The facts to be stated refer to the occurrence of water at various depths, that reached to or flowed over the surface. These depths will now be stated, with notes as to their relative position:

(*a*) Fresh water was found at the depth of 75 feet. This occurs in a gravel and coarse sand that underlies a stratum of mud or clay a few feet thick, from which the writer has obtained a considerable variety of marine diatoms. Over this again lies a gravel with large

stones, some of which contain Devonian fossils, showing that they must have been originally derived from beds elsewhere and very much older than any in southern New Jersey.

As noted in the report of wells on the mainland near Absecon (see top of page 283), an exactly similar arrangement of strata was there passed through, including the occurrence of similar forms of marine diatoms. The microscopic study of these diatoms shows that they differ so much from those found in the thick beds of clay associated with the deep wells, and frequently alluded to in this and former reports, as to be indicative of a different geological age, and, as may be inferred from their position as well as their close correspondence to living diatoms, of a much later age.

(*b*) Salt water was found at the depth of 115 feet. The marine character of the water, considered in connection with certain changes in the character and color of the next lower sands and clays, inclines the writer to the view that this depth marks the termination of the recent beds and the commencement of a series of strata that have been referred to the Quaternary in former reports.

Water that overflowed and was also salty or became so upon pumping was found at the depths of 225, 270, 276, 280, 300, 325 and 328 feet; that at 300 feet was remarked as especially irony.

That at 225 feet occurs in strata composed of sands and clays, yellowish brown in color, some of the sands much resembling a good quality of brown sugar, both in color and in the size of the grains or granules; very coarse gravel is, however, sometimes interbedded. These strata are in the Quaternary division, shown in former annual reports to terminate at about the depth of 265 feet.

The water from the remaining depths noted—that is, from 270 to 328 feet, inclusive—occurs in sands referred in the same reports to the Micocene, which sands overlie the great artesian diatomaceous clay bed.

It may be that some of these horizons might yield fresh water inland and thus become available as a source of water-supply, especially near the coast, from Absecon south, and possibly along the beaches of Cape May county and also in the State of Delaware and the eastern shore of Maryland.

Mr. Robinson also noted more or less wood from 115 feet downward, also heavy gravel at 216 feet, and coarse, black sand at 245 feet.

ARTESIAN WELL, OCEAN CITY.

During the early part of the summer of 1892 a well was put down by Uriah White for the Ocean City Water Works. Notes and a full series of samples of the strata were furnished by the engineer in charge of the drilling and with the consent of the contractor. A careful examination of the specimens has been made. As noted below, fossil shells were observed, while the microscope revealed marine diatoms which cannot be seen without considerable magnifying power. Both the shells and the diatoms show the beds below the superficial sands to be of Miocene age. The following is the record :

Beach sand, recent shells at the base...	30 feet.	30 feet.	Recent.
Sand	85 "	115 "	
Sand, with thin clay seams.	60 "	175 "	Quaternary.
Sandy clay	10 "	185 "	
Fine gravel and sand, with streaks of clay	93 "	278 "	
Bluish, sandy clay, solid	40 "	318 "	Miocene, not diatomaceous.
Sand, with *water*	16 "	334 "	
Bluish, sandy clay, with small shells...	32 "	366 "	
Seam of sand, with *water*	5 "	371 "	
Gray sand, with small shells	29 "	400 "	Miocene, diatomaceous.
Bluish, sandy clay, diatomaceous	112 "	512 "	
Gray sand, with water..	16 "	528 "	
Bluish, sandy clay, diatomaceous	72 "	600 "	
Brownish, sandy clay, hard, with shells and diatoms	55 "	655 "	
Brownish clay, with hard streaks described as crusts	5 "	660 "	
Gravel and sand, with a considerable number and variety of small shells,	20 "	680 "	
Clayey sand	5 "	685 "	
Sand, with wood, shells and *water*	5 "	690 "	Miocene, not diatomaceous.
Micaceous clay, no diatoms	5 "	695 "	
Sand, with wood and shells, *water* at 720 feet	45 "	740 "	
Clay, with small shells, no diatoms	20 "	760 "	

There is a close correspondence in the materials passed through in this well and in the wells at Atlantic City, ten and one-half miles to the northeast. There are, however, some slight differences in the character of some of the beds, These correspondences and differences

will now be noted. No large gravel-stones were obtained in the first 115 feet; this, however, may have been for want of sufficient pressure of water used, in the hydraulic method employed, to bring these to the surface. Such gravels have been found at various depths between 50 and 90 feet, at most localities along the beaches from Beach Haven to Cape May, and in fact were found between the depths of 70 and 84 feet in an unsuccessful boring made on an island in Great Egg Harbor bay, at a point but two miles to the northeast.

The gravels and sands occuring next below the depth of 115 feet, referred to the Quaternary, at Atlantic City, and which end there at the depth of about 265 feet, terminate here at the depth of about 278 feet.

The strata between 278 feet and 371 feet contain more clay than at Atlantic City, where the corresponding interval shows mostly sand.

The great diatomaceous clay beds, heretofore demonstrated to occupy the section at Atlantic City from the depth of 380 feet to that of 680 feet, occur here between the depths of 371 and 685 feet. These beds are generally more sandy than at Atlantic City. In consequence of this difference, shells were washed up in more perfect condition than at Atlantic City, where, owing to the greater toughness of the clays, the drill necessarily ground such into minute, unidentifiable fragments.

The existence of these beds from Waretown, N. J., to Richmond and Petersburg, Va., beneath the comparatively level plain bordering the Atlantic ocean, is now known. Their average thickness is at least 300 feet. Elsewhere in this paper there is noticed a thickness at Great Sedge island of 225 feet, at Waretown of 200 feet, at Atlantic City of 300 feet, while for this well the thickness as learned from careful microscopic study of the borings is 314 feet.

A well being bored at this writing at Beach Haven but not finished nor entire details yet known, shows a thickness of 250 feet. Borings obtained from two wells at Crisfield, Md., indicate a thickness there of about 400 feet, with the occurrence of a streak containing the characteristic forms of the Miocene period at about 200 feet above the main bed, which there occupies the interval of 385 to 790 feet.

As at Atlantic City, the next group of strata, occupying here the interval between 695 and 760 feet, becomes non-diatomaceous.

The following water horizons of Atlantic City were found in this well at different though at correspondingly-equivalent depths, thus:

Water Horizons.	Depth at Atlantic City.	Depth at Ocean City.
In the sands above the diatomaceous clays,	270 to 328 feet.	334 and 366 feet.
In the central sands of the diatomaceous clays......	525 "	512 and 528 "
In the lower sands of the diatomaceous clays......	Not known.	685 ".
In the sands below the diatomaceous clays......	700 to 720 feet.	720 "

This well is not more than one-half mile southeast of the line of strike of the strata at Atlantic City, hence the close correspondence. The drilling was prospected to 760 feet, but the water-bearing sands utilized were found higher, and the well was finished with a depth of about 720 feet. Some small shells, both bivalves and univalves, were found near the lowest point attained, which must have very nearly reached to the Perna shell and clay bed that occupies, at Atlantic City, the next interval of 40 feet, below which there is another water-bearing horizon, from which two wells at Atlantic City draw a copious supply.

WELL AT FIFIELD'S, ON LADD'S HUMMOCKS IN GREAT EGG HARBOR BAY, OPPOSITE LONGPORT.

This well was bored in 1891 to a depth of 397 feet, and was then abandoned. It undoubtedly entered the top of the diatomaceous clay bed, in which water would have been found had the work been continued, its presence in these beds having been abundantly proved by the wells sunk at Atlantic City and Ocean City, both upon nearly the same line of strike with this, the one locality being eight miles to the northeast and the other but two and one-half miles to the south.

The following carefully-kept record was furnished by Mr. Fifield:

Beach sand......		40 feet.	Recent.
Mud, some shell......	10 feet.	50 "	
Coarse gravel......	8 "	58 "	
White clay......	2 "	60 "	
Coarse gravel and sand......	6 "	66 "	
Dark clay......	4 "	70 "	
Coarse gravel......	14 "	84 "	
Water at 84 feet.			
Gray sand......	76 "	160 "	Quaternary.
Gray sand, with wood......	4 "	164 "	
Gray sand......	101 "	275 "	
Greenish clay......	19 "	294 "	Miocene, the lower 25 to 50 feet, probably diatomaceous.
Coarse sand and fine gravel......	52 "	346 "	
Greenish-blue clay, solid......	51 "	397 "	

There is a close correspondence in the succession and character of strata throughout, with the same as recorded for the wells at Atlantic City. The lower part of the first 84 feet also corresponds closely with the records for the wells at Absecon. The resemblances may now be noted.

The mud at the depth of 40 feet was noted at Atlantic City. The coarse gravel at 50 to 66 feet, with the interbedded 2 feet of white clay, occur on the mainland near the shore road, where the clay is used for brickmaking. The 4 feet of dark clay at 66 to 70 feet, and the coarse gravel below, containing water, are almost certainly the equivalents of the diatomaceous clay and the water-bearing gravel below it, found in the shallow Absecon wells. This horizon occurs at Atlantic City at the depth of 75 feet or more. For further notice of this diatomaceous clay, recent, geologically, in age, see the report next following of the wells at Absecon. The greenish and bluish clays from below 275 feet to the base, represent the Miocene, and one-half, if not all, of the lower 51 feet, described as solid bluish clay, is undoubtedly the top of the 300 feet of Miocene diatomaceous clays associated with the deep wells, and which is much older than the diatomaceous stratum just noted near the surface.

ARTESIAN WELLS NEAR ABSECON.

For many years the Atlantic City Water Company, commonly known as the old company, has been supplying Atlantic City with water brought in pipes across the meadows from a point on the mainland, near the shore road, and located midway between Absecon and Pleasantville. The water plant at this place is supplied from a number of artesian wells, 24 feet deep. They are located upon a low piece of ground, but little above high tide. There are two receiving basins whose floors are about on sea level, and whose sides are banked sufficiently high to keep out any incursions of sea-water from the adjacent creek or any inflow from the surrounding surface. From the floors of these basins were sunk the artesian wells, which overflow naturally into these reservoirs. There are 22 wells in one basin and 32 in the other.

The beds penetrated by the wells are—

Heavy white gravel, with fossiliferous pebbles..	9 feet.
Bluish clay, containing marine diatoms, recent species geologically	9 "
Coarse sand, with water	6 "
Total depth...	24 "

This section is especially interesting, since the marine diatoms noted are generally of so recent an appearance as to indicate at once to any experienced diatomist that the clay in which they are found was laid down not only comparatively recently geologically, but also that it must be an entirely different stratum from the great 300-feet diatomaceous clay bed associated with the numerous deep wells in southern New Jersey.

The conclusion, furthermore, seems irresistible that the heavy gravel with fossiliferous pebbles must have been placed on the top of the clay by a working over and re-depositing of the Quaternary yellow gravel and sands of the higher ground to the westward.

The author, as is noted in this report, page 287, has traced for three miles along the shores of the Great Egg Harbor river, near Mays Landing, a bed of clay containing a somewhat similar assemblage of diatoms, and likewise overlaid by gravels with fossiliferous pebbles. The dip of this clay stratum is scarcely six feet per mile.

C. W. Coman has also furnished the Survey with specimens of clays from near the banks of the Maurice river, at Buckshutem, and from the banks of the Cohansey river, at Bridgeton, which, on examination under the microscope, also exhibited diatoms.

The diatoms at these three localities were mixed marine and fresh-water forms, the marine predominating; but few fresh-water forms, however, were seen in the Absecon wells deposit. Strewn mounts of the diatoms from Absecon were submitted to C. H. Kain, an acknowledged authority upon their specific forms. He writes: "The species are almost exclusively marine; very rarely a fresh-water form is seen. I can discover no species not now to be found in the mud of Absecon marshes. The abundance of circular [disc] forms, however, suggests a fossil deposit, although I can find no form which is now only found in the fossil state. I should suspect the deposit to be of comparatively recent formation. It greatly resembles in this respect the Bridgeton and Buckshutem deposits, although both of the latter contain a much greater proportion of fresh-water forms. The Abse-

con deposit may not be any more ancient, but probably it was not so much within the reach of fresh-water influences."

These facts suggest some interesting relations between these various deposits. Additional careful investigation, especially in the field, will be needed, however, before their exact bearing upon each other can be fully defined.

The wells at Atlantic City, after penetrating about 40 feet of beach sands and 10 feet of mud, the probable bottom of an old channel, enter a succession of gravel and clay beds which the author deems the equivalent of these at Absecon, a conclusion reached after careful study.

So much of the Atlantic City section as may be needful to show its relation to the Absecon wells will now be given:

Record.				Age.
Beach sand		to	40 feet.	Very recent.
Mud, foraminifera and diatoms	40	"	50 "	
Heavy gravel, fossiliferous pebbles	50	"	58 "	Recent.
Clay, recent marine diatoms	58	"	63 "	
Heavy gray gravel, fossiliferous pebbles, fresh water	63	"	72 "	
Clay, recent marine diatoms	72	"	75 "	
Gray sand and gravel, water	75	"	86 "	
Fine and coarse sand	86	"	105 "	Probably also recent.
Heavy gray gravel	105	"	109 "	
Streaks of gray clay and sand	109	"	116 "	
Alternations of fine and coarse sands and gravels	116	"	265 "	Quaternary.
Most of the strata of this division are yellowish in color and contain no micro-organisms.				
Salt water at 116 and 225 feet.				

The similarity of the assemblage of diatoms in the clays from the Absecon wells with those noted above in clays at 58 to 63 feet, and again at 72 to 75 feet, considered in connection with the alternations of gravels with fossiliferous pebbles, suggests an identity of strata at the two localities.

The water at the water-works plant at Absecon is fresh and wholesome, as proved by its long use at Atlantic City. Its original source where it enters the sand that dips beneath this recent diatomaceous clay bed is probably not very distant. This water horizon, however, under the beaches has not been considered satisfactory, and it or some

horizons very closely related to it have been tried at a number of points between Atlantic City and Cape May. It was met with in Fifield's boring (see page 281) at the depth of 84 feet, associated with a similar succession of beds as at Atlantic City. In the absence of specimens of the clays, however, the presence of diatoms, which most likely occurred there, cannot be positively asserted.

Fresh-water springs, long known and used by boatmen for filling their casks, occur at various points in the marshes between the beaches and the mainland. One such may be noted on Barrel island, in the bay near Beach Haven, and another, until recently, on Peters' beach, near Atlantic City. The storms, however, have washed away a large portion of this beach and buried this spring beneath the waters of the inlet. These springs are probably fed from this Absecon artesian horizon.

The writer is inclined to class as of the same geological age with these recent diatom beds the gravels and sands below them to the depth, at Atlantic City, of about 115 feet, at which point he would place the dividing line between these and the underlying Quaternary sands, clays and gravels, for these reasons: (1) The beds change from a generally gray cast to a prevailing yellowish hue; (2) the water from the gray beds at Atlantic City is fresh, while that from the yellow beds is salt.

ARTESIAN WELL AT PORT REPUBLIC.

During the spring of 1892, a two-and-one-half-inch well was bored for Capt. E. W. French, at Port Republic. No continuous record was kept nor any specimens of the borings saved. Water was obtained and cased off at a depth of 114 feet, at the bottom of what is described as a black sand, 33 feet in thickness. Further down near the bottom a bluish clay, 13 feet thick, was passed through, beneath which, in a bed of coarse gravel, a flow of "soft, pure water" was obtained at the depth of 151 feet. The blue clay undoubtedly represents the diatomaceous clay bed.

The water horizon at 151 feet is the probable equivalent of that which occurs in the upper part of the miocene diatomaceous clay bed at Atlantic City at the depth of 406 feet. The water at 114 feet *may* possibly belong in the sands above the diatom clays and represent the lower portion of the group of water horizons there, one of which occurs at the depth of 328 feet at Atlantic City.

ARTESIAN WELLS AT PORT NORRIS AND BIVALVE.

In past annual reports notices have appeared of two wells near Port Norris with depths of about 200 feet and one well in the town with a depth of 78 feet. On a personal visit to the region, another flowing well was also found in the town, with a depth of but 37 feet. The two deep wells are located upon either side of Maurice river, about one mile below the town, the locality being now called Bivalve. The ground is scarcely elevated above high tide. The two more shallow wells in the town of Port Norris proper are upon ground about eight feet above tide. A few years since the writer obtained some of the borings from the bottom of one of the deep wells and found therein marine diatoms that showed that the artesian diatomaceous clays had been entered. Consistently with a dip of 25 feet per mile, the horizon here represented must be the equivalent of that in the upper part of the diatomaceous clay and found at Atlantic City at 406 and 430 feet.

Consistently also with the same amount of dip the wells of 37 and 78 feet depth would represent the group of water-bearing sands in miocene strata next above the diatomaceous clays, and found in borings at Atlantic City at several points between 270 and 328 feet.

Until, however, we have more knowledge of certain recent deposits lately found near the surface and bordering the Atlantic ocean, and also along the banks of the Great Egg Harbor, the Maurice and the Cohansey rivers, it may be well to withhold a too positive reference of the exact horizons reached by the shallow artesians at this point.

ARTESIAN WELL AT MAYS LANDING.

During the summer of 1892, an artesian well of six inches diameter was drilled at Mays Landing by the Mays Landing Water Power Company, under the direction of Superintendent J. W. Wells, who courteously notified the writer of the commencement of the work and furnished specimens taken at frequent intervals. The well reached a depth of 176 feet and has a flow of 25 gallons per minute. The temperature is 56°.

Two wells of two and one-half inches diameter had been previously put down by the same company. These are noted in the Annual Reports for 1884 and 1885, in which it is stated that one well has a depth of 130 feet and flows four gallons per minnte, and the other a depth of 150 feet and flows seven gallons per minute.

All the wells are situated upon a level strip of ground bordering the Great Egg Harbor river, the elevation being about eight feet above tide.

Only a very short distance from the location of the wells the ground rises about seven feet higher. Had the wells been sunk upon this higher ground, there would first have been encountered about two feet of yellow gravel and under this five feet of yellowish-white clay. Both these strata have been carried away from the strip nearer the river by erosion, and are therefore missing from the well record. The yellowish-white clay was traced along the shores of Lenape lake, the euphonious name of the water-power there, from an elevation of 18 feet at a point two miles north of Mays Landing to a point at tide-water level one mile south at High Bank landing, thus indicating a dip of scarcely six feet per mile. Microscopic examination was made of samples of this clay taken at a number of points along this distance and on both banks of the river, and every specimen was found to contain a mixture of marine and fresh-water diatoms, the marine preponderating. The general assemblage of species of the diatoms shows such a marked difference from the assemblage of such forms in the great 300-feet *miocene* diatomaceous bed, associated with the deep artesian water horizons, as to indicate an entirely different geological age, and, as may be inferred from their position, a much later one. This bed is referred to in connection with the report upon wells near Absecon (see page 283).

The section at these wells is as follows:

Yellow gravel	On higher ground, south of the well.		Recent.
Yellowish-white clay, recent species of diatoms			
Gray sand, granular	at 22 feet.		Miocene. (?)
Gray sand, finer	to 54 "	54 feet.	
Bluish-gray clayey sand, considerable wood, well preserved	18 "	72 "	Miocene.
Bluish clay, diatomaceous	26 "	98 "	
Clayey sand, diatomaceous	14 "	112 "	
Sand, bluish when wet	4 "	116 "	
Alternations of sand and diatomaceous clay	9 "	125 "	
Sand, water	7 "	132 "	
Sandy clay, diatomaceous	10 "	142 "	
Bluish clay, diatomaceous	7 "	149 "	
Sand, *water*	2 "	151 "	
Alternations of sand and diatomaceous clay	14 "	165 "	
Blue clay, richly diatomaceous	7 "	172 "	
Sand, *water-bearing*	4 "	176 "	

All the clays below 100 feet contain diatoms characteristic of the miocene clays, and, as already noted, quite distinguishable from those in the surface bed above described.

The water horizon of these wells, 130 to 176 feet, is identical with that at Weymouth at the depth of 40 feet. The distance between the two places is five miles and their relative position nearly directly across the lines of strike. This water-bearing stratum is also the equivalent of that in the central portion of the diatomaceous clays at the depth, at Atlantic City, of 525 feet.

ARTESIAN WELL AT HARRISIA, FORMERLY CALLED HARRISVILLE.

This well, bored in 1866, was noted in the Annual Reports for 1879, 1882 and 1885, but only a general statement was made as to the nature of the strata passed through. In the year 1891, the writer learned that Mahlon Broon, employed at the time at the paper mills adjacent, and who assisted in the work of boring, had made a record, which he still kept. A letter addressed to him brought a reply with a copy of the record. It is as follows—on the right is noted the author's geological interpretation and correlation of the beds with those at Atlantic City. The words bracketed are introduced by the author:

RECORD.			NOTES.
Surface sand to		77 feet.	The upper portion of this probably recent.
Sand like that in the creek	8 feet.	85 "	Miocene diatomaceous clays.
Blue mud	13 "	98 "	
Clay, with metal [probably iron pyrites]	10 "	108 "	
Marly mud	16 "	124 "	
Strata with old wood.	7 "	131 "	
Mud and shells	15 "	146 "	
Hard rock [probably sandy clay cemented]	50 "	196 "	This division includes, probably, the base of the diatomaceous clays, together with the underlying non-diatomaceous clays and the water-yielding sands next below, the equivalent of those at 700 to 720 feet at Atlantic City.
Sand and boiling spring-water,	35 "	231 "	
Dark, slushy sand	14 "	245 "	This division probably corresponds with beds at Atlantic City, named in order, thus: Perna marl. Brown sands. Chocolate clay. Green marl.—Shiloh bed.
Yellow sand	16 "	261 "	
Coarse red sand	45 "	306 "	
Dark sand	12 "	318 "	
White clay	13 "	331 "	
Green marl, *irony water*	37 "	368 "	
Slate stone (?)	8 "	375 "	

The annual reports before noted state that the water obtained was "strongly impregnated with iron." The well is certainly a strong mineral spring and is still flowing. It draws its supply from within a marl or a marly-clay stratum.

A careful comparison of the record with that of the well at Winslow as given in the Geology of New Jersey, 1868, and somewhat more minutely by Prof. G. H. Cook in the Annual Report for 1855, convinces the writer that there is considerable similarity in the two, and that had the drilling been continued through the marl or marly clay to an additional distance of from 75 to 100 feet, there would have been found the same excellent water stratum that supplies the deep well (335 feet) at Winslow, and which is probably the equivalent of that at 950 feet beneath Atlantic City.

It is also interesting to note that the water shown by the above record to have been passed at 196 feet agrees closely with the statement made by the owner, R. C. Harris, as recorded in the annual reports before mentioned, that further on than 180 feet "a gravelly bed was found and water suddenly spouted up, reaching to the top of the tubing, eight feet above the ground." This depth, 196 feet, also closely agrees with the calculated depth at this point, 188 feet, for the occurrence of the 700-feet Atlantic City water horizon, said calculation being based upon a dip of 25 feet per mile.

A personal interview was recently had with Mahlon Broon, when he stated that the well, eight inches in diameter, was bored with an auger by means of horse-power, and that the core was brought out quite solid and entire by the apparatus used. In consequence, fossil shells quite large and perfect were obtained. Among these he described oyster shells six to eight inches long and as broad as one's hand, evidently a ponderous oyster of past ages. It is to be regretted that none of these oyster or other shells are now to be had, as they would most likely aid in positive determination of the exact beds passed through. The various sections of iron casing placed in the well were joined by introducing the adjacent ends of each section into a heated iron band or collar, which, on cooling, firmly clasped them together—a contrast to the present method, in which the joints are made by screwing the end of one section into a collar upon the upper end of the last one placed in the well.

ARTESIAN WELL AT GREAT SEDGE ISLAND, IN BARNEGAT BAY, NEAR TO AND NORTH OF BARNEGAT INLET.

Property of L. W. Warner.

In the early part of 1892 a well was put down by Uriah White on the above-named island. M. W. Warner, son of the owner, watched the boring with interest, and on the completion of the work courteously forwarded the following columnar section and record, wisely writing that "it might prove useful for others who intend sinking wells, as well as aid in making computations relative to dip." Subsequently the writer visited the well, obtained specimens of the clays from various depths, and, on examining these under the microscope, found marine diatoms characteristic of the miocene diatomaceous clays heretofore reported from wells at Atlantic City and at numerous other places in southern New Jersey. As the result of this visit and of personal inquiry upon the spot, the conclusion was reached that most of the clays from the depth of 36 feet downward contained diatoms. Hence, it seems probable that there is here represented at least 225 feet of the diatomaceous clay bed.

COLUMNAR SECTION OF ARTESIAN WELL AT GREAT SEDGE ISLAND, NEAR BARNEGAT INLET, IN BARNEGAT BAY, N. J., PROPERTY OF L. W. WARNER, ESQ.

Sedge	2	feet.
Blue mud	3	"
White sand	15	"
Hard crust, white sand	1	"
White sand, with small sea-clam shells, excellently preserved	15	"
	36	"
Sand and marly clay	4	"
Marly green clay, very tough, with gravel, size of peas	5	"
Green marl or clay, with small shells, sea clam	5	"
White sand	7	"
Ginger-colored clay and bits rotten wood	1	"
	58	"
Gray clay	19	"
	77	"
Green clay	3	"
Gray and black sand	10	"
Gray clay and rotten wood	4	"
Chocolate-colored clay	6	"
	100	"

Gray and black sand	20 feet.
Brown and gray clay, small quartz imbedded, transparent	30 "
	150 "
Hard crust, white sand	1 "
White sand, coarse gravel and rotten wood (water, at 157 feet 10 inches, 1 gallon per minute)	9 "
Fine white sand and many specks like mica	10 "
Fine white sand and many specks like mica (water, 2 gallons per minute)	5 "
	175 "
Fine white and gray sand and many specks like mica, also quartz	5 "
Black mud, white and black sand, mica, vermilion sand	8 "
Fine and coarse white and black sand, mica	8 "
Fine and coarse white and black sand, mica and bits wood	4 "
	200 "
Fine white and black sand and very coarse white quartz	25 "
Coarse red and white sand and fine gravel	3 "
Fine gravel and fine and coarse sand, bits wood	16 "
Gray clay, tough	1 "
Coarse sand and fine gravel (water, 2 gallons per minute)	7 "
	252 "
Gray, clayey marl, medium gravel and quartz and rotten stone, brown	8 "
Brownish-gray clay and bits rotten wood	10 "
Fine and coarse sand, some like opals; bits wood	10 "
	280 "
Hard, sandy, brown clay	10 "
Hard, muddy, brown clay	3 "
	293 "
Coarse and fine white and gray sand, some mica	27 "
	320 "

(Water, 10 gallons per minute. Bottom of 4½-inch pipe is 300 feet down; screen point is 20 feet below that.)

Above notes by W. M. Warner.

The small flows of water noted at 157 feet and 175 feet seem to represent the horizon of 525 feet to 550 feet at Atlantic City, since a calculation based upon a dip of 25 feet per mile would place it here at the depth of 150 to 175 feet. This horizon is the central one of the diatomaceous clay bed. The other small flow at 252 feet probably represents some water-bearing sands in the lower part of the same clay bed—an horizon not so far reported from Atlantic City, but noticed at Ocean City, and believed to be stratigraphically the same as the sands supplying the wells at Pleasant Mills, N. J.

The water horizon (300 to 320 feet) utilized by this well is the equivalent of that at the depth of 700 feet at Atlantic City, being the first water-bearing sands fairly below and out of the diatomaceous clay.

As noted by M. W. Warner upon the section, the flow is ten gallons per minute. In a letter he states that the "well, on pumping, supplied one hundred gallons per minute steadily for over an hour and still did not lower in the pipe;" also that "the temperature is 55°." He further states that a log one foot in diameter was drilled through at the depth of 270 feet and that "the water will rise above the level of the bay nine feet."

Some months later he informs that "a marked increase in the flow is noticed 24 to 36 hours after heavy rains," an interesting fact.

Two complete analyses were made of the water by competent chemists, one early after the completion of the well and the other quite recently, or about one year later. They correspond with each other quite closely as to the nature and relative proportion of the ingredients, but the first showed nearly double the quantity of mineral matter per gallon, the amounts respectively being 8.694 grains and 4.633 grains per U. S. gallon. The later analysis was made by Dr. Henry Leffmann, a sanitary expert, who furnishes a copy as follows:

Calcium carbonate	.937	grains.
Silica	1.624	"
Potassium sulphate	.691	"
Sodium sulphate	.274	"
Sodium chloride	.466	"
Sodium carbonate	.266	"
Magnesium	.207	"
Iron	.168	"
Total to U. S. gallon	4.633	"

Nitrogen as nitrites	None.
Nitrogen as nitrates	Trace.
Nitrogen as ammonium	0.0005 grains.
Nitrogen as permanganates	0.0034 "

It should be added that Dr. Leffmann recommends the water for domestic use and that the owners are delighted with it. The increased purity of the water with time is interesting. The change is said to be noticeable to the taste of those using it. Dr. Leffmann verified his work by obtaining a second sample and making additional tests, which only proved the first.

ARTESIAN WELL AT WARETOWN.

In the year 1891 a four-inch artesian well was bored at Waretown, N. J. The depth reached was 280 feet, and a flow of about 20 gallons per minute was obtained. The well is located on a gravel bank facing Barnegat bay, the elevation being not greater than 10 feet.

A generalized description of the strata was furnished by Capt. J. W. Birdsall; it is as follows:

Gravel and sand	10 feet.	10 feet.
Brownish clay	20 "	30 "
Blue clay	40 "	70 "
Alternations of black mud and black sand, changing near the bottom to gravel and white sand	210 "	280 "

At the depth of 70 feet there was a small flow of water that rose six or eight feet above the surface. At 137 feet there was another small flow which rose but two feet above the surface.

Specimens of clays still remaining around the mouth of the well were collected early in the summer of 1892 and found on microscopic examination to contain the forms of diatoms characteristic of the 300-feet diatomaceous clay bed of the Miocene period. This bed is probably entered at the depth of 10 feet, and certainly at that of 30 feet; allowing 25 feet at the bottom of the well to represent the non-diatomaceous clay stratum found beneath the diatom bed at Atlantic City, there would be left as the thickness of the diatomaceous clays at this locality upwards of 200 feet.

This is the most northerly point to which this bed has so far been

positively proven. It may, however, be expected farther north along the coast; in fact the lower half of the bed was *probably* passed through at Berkeley Arms.

The water horizon used is identical, stratigraphically, with that at Great Sedge island and the equivalent of that at the depth of 700 feet at Atlantic City.

ARTESIAN WELL AT VINELAND.

A well of four inches diameter was completed during the winter of 1889–90 for Kimball, Prince & Co., at Vineland, N. J., to obtain water for use in the boilers at their sash and planing mill. Its depth is 205 feet below the surface, which has an elevation of about 105 feet. The amount of water obtained is 1,200 gallons an hour. A record of the thickness of the various beds encountered was not kept, because the value of such data was not known to those financially interested. Fortunately, however, a few specimens that had attracted attention had been laid aside. A set of these was cheerfully furnished by W. V. Prince, with information as to the depth from which each came.

DESCRIPTION OF SPECIMENS.

Black clay	52 or 57 feet.
White and blue clay in layers and containing considerable wood	116 to 126 "
Greenish clay, from the base of the bed	at 197 "
Brownish and reddish-brown sand, in which water is found	to 205 "

The water rises to within 17½ feet of the surface, or six inches lower than the surface-waters rise. As there are no artesian wells in southern New Jersey in which the water rises so high above sea-level, it seems scarcely possible that this well draws from between Miocene strata. No micro-organisms could be found in any of the earths except in the sand from the bottom, where a few sponge spicules were observed, which may indicate that the deposits there were mixed with some Miocene strata, worked over and re-deposited. The upturned edges of the Miocene cannot, however, be much deeper.

ARTESIAN WELLS AT ATLANTIC COMPANY'S CRANBERRY BOGS, TWO MILES NORTH OF WEYMOUTH.

Elevation, 40 feet.

Two wells, depths 40 and 45 feet. Water rose within 10 feet of the surface.

White clay	6 feet.	6 feet.
Iron crust	8 "	14 "
Diatomaceous sandy clay	31 "	45 "

These wells were sounded and the diatomaceous * character of the clay as above noted proved under the microscope. The water-bearing stratum reached is the same as that supplying the wells at Weymouth, and the equivalent of the 525 feet horizon at Atlantic City. These wells are now filled up. They were bored in the hope of obtaining an overflow of water with which to annually cover the cranberry vines, as is the usual custom. The elevation of the surface being too great this expectation was not realized.

ARTESIAN WELLS, HORNER'S BOG, FOUR MILES NORTH OF WEYMOUTH.

Elevation, 50 feet.

There were two wells bored at this locality some years since, the depth reached by each being respectively 96 and 106 feet. The one having the greater depth was not only deeper by measurement but was more than correspondingly deeper stratigraphically. Its record, furnished by the superintendent of the bog, Aaron Carney, is as follows:

White sand	4 feet.	4 feet.
Yellow hardpan	2 "	6 "
White clay	6 "	12 "
Quicksand and gravel	65 "	77 "
Blue clay and pebbles	18 "	95 "
White gravel	11 "	106 "

* The diatoms were covered with a yellow metallic coating of iron pyrites.

The Miocene strata were probably entered at about the depth of twelve feet. The blue clay noted was almost certainly diatomaceous. No specimens, however, were obtainable by which this fact could be absolutely proven.

In the white gravel at the bottom water was found, which rose to within about two feet of the surface. A ditch was therefore made, some three feet deep, which led to the lower ground of the adjacent cranberry bog. The water then overflowed and passed off through this channel for thirteen days, when the well became filled up, and has been permitted to remain so ever since.

Taking into consideration the elevation of the ground, the depth of the well, the strike of the beds underlying southern New Jersey, and the dip of 25 feet per mile as everywhere noted for these Miocene wells, the water horizon reached must be that of the Pleasant Mills wells, and which occurs in the lower part of the 300-feet diatomaceous clay bed—an horizon not as yet reported at Atlantic City, but probably the same as one passed in a boring at Ocean City at the depth of 685 feet.

ARTESIAN WELL, BARGE'S CRANBERRY BOG, NEAR PLEASANT MILLS.

Elevation, 20 feet.

A well was sunk a number of years since about one-half mile west of Pleasant Mills, in Barge's cranberry bogs. It reached a depth of 201 feet, but was not deemed successful, as it did not overflow. It has filled up since, probably because not finished properly. A flow of water has been reported as having been passed at about the depth of 57 feet. This was probably the Pleasant Mills water stratum, which belongs in the lower part of the 300 feet of diatomaceous clays.

Judging from the dip of the Miocene strata to which the diatom and associated beds belong, the dip being regarded at about 25 feet per mile, the boring must have closely reached the 760-feet horizon of Atlantic City. This conclusion is corroborated by a microscopic examination of the sands and a few clay lumps from the bottom of the well, which were found still remaining around its mouth and which contained no diatoms, showing that the diatom beds had been entirely passed through. The Atlantic City water horizon of 700 feet was also probably passed in this well.

ARTESIAN WELL, ROCKWOOD'S BOG, FIVE AND ONE-HALF MILES NORTHWEST OF PLEASANT MILLS.

Elevation, 45 feet.

This well is noted in the annual report for 1885. It is there stated that it "was sunk to the depth of 158 feet through beds of sandy clay and sand but no satisfactory supply of water was got." C. G. Rockwood has recently furnished the following memoranda preserved by him:

Different kinds of sand	13 feet.	13 feet.	Recent.
Sand	8 "	21 "	
Sand and clay, milky water	9 "	30 "	
Quicksand	18 "	48 "	Miocene.
Quicksand and clay	9 "	57 "	
Black clay	9 "	66 "	
(A) Coarse gravel, full of iron	32 "	98 "	
Mud or muck	17 "	115 "	
(B) Sand, gravel and more iron	43 "	158 "	
Boring discontinued.			

Water described as very irony occurs in the gravels marked A and B.

The location is west of the line where the base of the Miocene diatomaceous clays probably rises to sea-level; these clays are, therefore, most likely wanting in this well. Miocene strata belonging beneath the diatom bed would, however, seem to be reached at the depth of about 30 feet. The lower portions of this well must have entered the top of the clays and marls met with at 844 feet, at Atlantic City. These are the same unsatisfactory beds in which the boring at Harrisia was discontinued. The distance southeastward to the line of strike of the latter well is seven miles. Had the drilling of the wells at both these localities been continued, there would probably have been found the excellent water horizon opened many years since at Winslow by the first deep-bored well in southern New Jersey, the depth there being 335 feet from the surface, or equal to 215 feet below sea-level. This Winslow (335 feet) horizon is the probable equivalent of that at 950 feet beneath Atlantic City.

ARTESIAN WELLS AT WINSLOW.

During the year 1892 two wells were bored by Leach Bros. at Winslow, one at the hotel, to the depth of 145 feet, and the other for Geo. Cochran, to the depth of 135 feet. The surface is elevated here about 130 feet. The record, which answers for either well, was kindly furnished by the contractors, and is as follows:

Surface soil	2 feet.	
Fine clay	10 "	12 feet.
Fine sand	18 "	30 "
Yellow clay	8 "	38 "
Sand	7 "	45 "
Sand, with water	80 "	125 "
Black clay, Miocene	10 "	135 "
Blue sand, Miocene	3 "	138 "
Blue clay, Miocene	3 "	141 "
Red gravel, Miocene	4 "	145 "

Water rises within 40 feet of the surface. The black and blue clays and sands near the base probably belong to the Miocene strata. The water horizon is probably the equivalent of that at 760 feet at Atlantic City.

The first well bored in the southern part of the State was put down at Winslow about the year 1853. It reached a depth of 335 feet, as shown by columnar section published in the Geology of New Jersey for 1868, and opened a lower water stratum, which is probably the equivalent of that at 950 feet at Atlantic City.

Thus, besides the water noted on the accompanying record in the 80 feet of sand next below the depth of 45 feet, there are now known to be two other sources for this region, one below certain black and bluish Miocene clays at a depth of 140 to 150 feet, as shown by the above record, and which clays are noted in the columnar section, page 292, Geology of New Jersey, 1868; the other at the depth of 335 feet, also shown in the columnar section just referred to.

SUMMARY.

The sinking of the various wells within the area south of Berkeley Arms and Waretown, and east and southeast of Winslow, has thus far revealed the existence in the underlying Miocene strata of seven

more or less well-marked deep-water horizons and also of a few others higher stratigraphically but not so well marked, at least at Atlantic City, where their occurrence was first learned. These latter were found in sands that belong probably to the same age, and are mentioned because of their bearing upon the geological structure.

In a number of former annual reports a dip of about 25 feet per mile has been indicated for the Miocene beds in which these wells occur. Careful study of the data heretofore known, in connection with the additional information since obtained, confirms this estimate. Calculations based upon this amount of dip and upon the depth of each well and the distance apart of parallel northeast and southwest lines of strike drawn through each locality, show that each well draws from some one of the horizons noted. In fact, the more the well records were studied, and the specimens of borings and the description of strata at different points compared, the more did a dip of about 25 feet seem to harmonize therewith. On, however, drawing a vertical cross-section with this amount of descent, a few minor discrepancies showed themselves; these, it was seen, would disappear with a very slight increase in the inclination of the beds. Another section with a dip of 25½ feet per mile was then constructed and found to completely harmonize all the facts connected with the various wells. This section was drawn along a line from the neighborhood of Winslow to Atlantic City and Ocean City, on a horizontal scale of one mile to the inch, and a vertical scale of 100 feet to the inch. The plate map which accompanies this report shows the location approximately, as also the several well localities referred to in this notice of artesian wells.

The order and stratigraphical position of the seven marked horizons will now be noted. All but one have been found at Atlantic City. Only four, however, those the most decided, have been developed and used at that place, but all furnish water to wells at one or more localities.

The first of these deep-water horizons was found at Atlantic City, at the depth of 328 feet, in sands overlying the 300 feet of diatomaceous clay. It may, however, be viewed as a group, since Robinson's test-boring revealed several between it and 270 feet, all of them in the same sands.

The second horizon, which may also be viewed as a group, was opened at Atlantic City at the depths of 406 and 430 feet. This

horizon occupies thin sand seams in the upper part of the diatomaceous clays.

Both the above horizons, when first opened at Atlantic City and allowed their natural flow, yielded fresh water, but, upon being forced by pumping, both became salty. It seems quite possible that, skirting the border of the mainland, both may be made available as sources of water-supply. Two shallow wells at Port Norris may possibly draw from the 328-feet group. One well, that at Port Republic, probably draws from the 406-feet stratum of the second horizon.

The third horizon occurs at Atlantic City at the depth of 525 to 560 feet. From personal observation of the various borings made at this place, this interval may be stated to be occupied by thin sand seams interbedded between sandy clays. It is in the middle of the 300 feet of diatomaceous clays. This horizon supplies wells at the following places, viz., at Atlantic Company's bog, Weymouth, Barnegat Landing, Mays Landing, Harvey Cedars, also two wells at Beach Haven, having a depth of about 425 feet, and one well at South Beach Haven, depth 435 feet. It has been met with but cased off at Waretown, Great Sedge islands and Seven islands, the wells being continued to a lower water-yielding sand.

The fourth horizon has not been reported at Atlantic City. It occurs in the lower part of the diatomaceous clay bed. It furnishes a group of 18 wells at Pleasant Mills, and was also opened by a well at Horner's cranberry bog, south of Hammonton; the latter well not having been properly finished has filled up.

The fifth horizon is found in a gravel and coarse sand, at a depth of 700 to 720 feet, at Atlantic City. It is quite below the diatomaceous clays, being immediately under about 25 feet of a hard, brownish non-diatomaceous clay that intervenes, at least at Atlantic City, between it and the diatomaceous clays. This horizon supplies the wells at Millville, Waretown, Great Sedge islands and Ocean City.

As this paper is being prepared, information has been received that a well has been recently sunk at Beach Haven to a depth of 575 feet. This must also draw from this horizon. Records and specimens of the borings are promised by the contractor, Uriah White. Until these arrive and are studied further details cannot be given.

The sixth horizon is reached at Atlantic City, at the depth of 760 feet. Between the horizon last described and this one are about 40 feet of dark greenish and bluish clays and shell marls. The borings

at Atlantic City for this interval exhibit a considerable number of shells, among them a perna,* of a species especially characteristic of Miocene times. At about 750 feet occur brownish coarse gravels and sands, from which, by means of the sand pump, there were obtained at Atlantic City, besides the perna and other varieties of Miocene shells, a considerable number of well-preserved clam shells, smaller than the clam of commerce but closely resembling it, if, indeed, it be not the same specifically. This horizon (760 feet) furnishes two wells at Atlantic City, and was probably met with in a well in Barge's bog. It likewise is the probable source of supply for two wells at Winslow, with depths of 135 and 145 feet. Both this horizon (760 feet) and the one above it (700 feet) yield much more water than that at 525 feet.

The seventh and last horizon to be noticed in connection with these Miocene wells was opened at Atlantic City, as already stated on page 277, at the depth of about 950 feet. From a careful study of the descriptions heretofore published of the beds passed through at Winslow and comparison of the same with the specimens of borings in hand from this part of the well at Atlantic City, there appears to be an identity in the order of succession and character of the beds. This identity is further corroborated by the similarity in the succession and character of the beds penetrated by the well at Harrisia. In view of these correspondences, and that the dip between the 335-feet water stratum at Winslow and that at 950 feet at Atlantic City agrees with the dip for the water-bearing sands higher up—that is, about 25 feet per mile—it may be reasonably concluded that but one water horizon is represented by these two wells.

II. WELLS IN THE REGION BORDERING THE DELAWARE RIVER.

The wells to be reported under this classification are located at Woodstown, Collingwood, Pavonia, Stockton, Hartford, Mount Holly, Medford, Columbus and Burlington. All these draw from Cretaceous strata. One well in Philadelphia will also be described, since it enters typical New Jersey beds of which a small remnant has been left upon the Pennsylvania side of the river.

* Perna maxillata.

ARTESIAN WELL BORED FOR ISAAC W. STOKES, AT MEDFORD.

This well was bored in 1889 (see report for that year, page 89) to a depth of 70 feet, but was continued the past year to 183 feet. The record is made up from the former annual report to 70 feet and below that from notes and specimens of the earths furnished by I. W. Stokes. The continuation of the boring was done by Stothoff Bros.

	Sand and earth	15 feet.	
(1)	Marl	30 "	45 feet.
	Sand, varying	15 "	60 "
	Shelly layers	4 "	64 "
	Coarse gray sand (*water irony*)	6 "	70 "
	(Depth of first well.)		
(2)	Green marl	15 "	85 "
	Black quicksand	25 "	110 "
(3)	Marl	12 "	122 "
	Quicksand	35 "	157 "
(4)	Marl (fourth stratum), at		170 "
	Sand, some clay	5 "	175 "
	Sand, some clay (*water good*)	2 "	177 "
	Sand	6 "	183 "
	(Cased to 179 feet.)		

Isaac W. Stokes writes that "the water is first-class, and rises to within 17 feet of the surface," and that "the supply seems inexhaustible."

ARTESIAN WELLS AT WOODSTOWN.

In the Annual Report for 1891, page 221, is copied the section of a well at this place, having a depth of 339 feet, in which is noted a sand 70 feet in thickness between the depths of 61 feet and 131 feet. It is also stated this sand contains no water. Investigation since then has proved this statement not well founded. In fact, the deep well of that report has been abandoned and closed up and there have been drilled six six-inch wells, arranged in a circle, each well about 200 feet from the next, all of which are supplied from this sand. The depths of these wells are as follows: No. I., 136 feet; No. II., 141 feet; No. III., 140 feet; No. IV., 143 feet; No. V., 149½ feet, and No. VI., 149 feet. They are upon ground nearly level, and having an elevation above tide of about 20 feet.

The record for one answers for all. It was furnished by Jacob H. Yocum, who also stated the depth of each well as above noted. The record is as follows:

			Equivalents.
Muck	8 feet.	8 feet.	Recent.
Limesand	8 "	16 "	Middle marl bed.
Green marl, with shell	34 "	50 "	
Cemented lime, sand and shell	4 "	54 "	
Fine gray sand, with water	80 "	134 "	Red sand bed.

The casing of each well was stopped in the cemented sand and shell, but the boring was continued to the bottom of the gray sand. The wells flowed over the tops of the casings about one foot above the ground. The average flow of each well is 60 gallons per minute. The temperature is 58°.

Kisner & Bennett, who bored all the wells, kindly furnished samples of the borings; they also furnish the record for the lower part of the deep well of last year. It is here inserted in order to complete our knowledge of the underground structure at this point.

Quicksand	52 feet.	186 feet.	Lower marl bed and clay marls.
Black sand marl.	60 "	246 "	
Black, muddy quicksand	30 "	276 "	
Blue clay, hard and tough	20 "	296 "	
White sand and water	43 "	339 "	

Kisner & Bennett also state that they prospected to the depth of 776 feet, where they found another water-bearing sand, and that they passed on the way down through alternations of sands and white and red clays. The water at 339 feet rose within 14 feet of the surface, and that at 776 feet within 18 feet.

ARTESIAN WELL AT MOUNT HOLLY AT DUNLAP'S CARPET WORKS.

RECORD FURNISHED BY C. G. ORCUTT, CONTRACTOR.

Dark muck	43 feet.		Lower Marl.
Sand and gravel, *small flow of water*	3 "	46 feet.	Clay Marls.
Dark muck	61 "	107 "	
Fine sand	4 "	111 "	
Dark muck or clay	134 "	245 "	
Sand, gray	5 "	250 "	
Dark, sandy clay	12 "	262 "	

Red clay	11 feet.	273 feet.	Plastic clays.
White clay	1 "	274 "	
Brown, sandy clay	20 "	294 "	
White clay	2 "	296 "	
Light, sandy clay	69 "	365 "	
Red clay	2 "	367 "	
Light, sandy clay	43 "	410 "	
Red clay	2 "	412 "	
Brown (?) clay	18 "	430 "	
Red clay	6 "	436 "	
Light, sandy clay	6 "	442 "	
Fine sand, gray; *small flow of water*	15 "	457 "	
Light sand, clay and sand	52 "	509 "	
Light, sandy clay	37 "	546 "	
Red clay	14 "	560 "	
Sandy clay and fine sand	48 "	608 "	
Yellow clay	3 "	611 "	
Brown clay	9 "	620 "	
Red clay	40 "	660 "	
Fine sand and a little brown clay mixed, *a little flow of water*	7 "	667 "	
Fine and coarse sand and some gravel,	8 "	675 "	

It will be seen that water horizons exist at say about 45 feet, 450 feet and 665 to 675 feet. It is possible some of these could be developed and used to advantage for general purposes, but as water of exceptional freedom from mineral ingredients was wanted for use in dyeing yarns, this well has been abandoned.

ARTESIAN WELL NEAR HARTFORD STATION.

Elevation of Surface, 70 feet.

A well was bored about one and one-quarter miles north of this station for Samuel C. Roberts, who caused to be preserved a complete set of samples. The boring did not prove a success; the record nevertheless has a geological value and is here given:

Yellow sand	39 feet.		Laminated sand. (?)
Micaceous sandy clay, light chocolate color	7 "	46 feet.	Clay marls.
Black mud or clay marl	54 "	100 "	
Green marl	17 "	117 "	
Clay marl	8 "	125 "	
Clay marl, similar to last	32 "	157 "	
Sandy clay	6 "	163 "	

Sand, fine, whitish gray	5 feet.	168 feet.	
Sand, darker gray	7 "	175 "	
Coarse, white sand and gravel with some mica	6 "	181 "	Sands at the base of the clay marl series.
The same, slightly coarser, color, blue gray	6 "	187 "	

This well was recorded in the Annual Report for 1890, page 265, to the depth of 167 feet, and was afterwards made deeper. The well was abandoned just above the water horizon that occurs at the base of the clay marls.

LORILLARD WELL, COLUMBUS.

Bored by Wm. Blaisdell to the depth of 356 feet. (See Annual Report, 1879, page 138.) Continued by Orcutt Bros. more recently to the depth of 715 feet.

The first part of the following record is copied from the report alluded to and the remainder is furnished by Orcutt Bros., who also preserved and presented a series of samples of the clays:

Yellowish, loamy sand, *water-bearing*	14 feet.		
Fine sand, somewhat mixed and colored with dark mud	34 "	48 feet.	Laminated sands and clay marls.
Stiff, black, sandy clay	24 "	72 "	
Fine sand, muddy, *water-bearing*	1 "	73 "	
Stiff, black, sandy clay	9 "	82 "	
Fine sand, *water-bearing*; scattered layer of sandstone or clay or shell rock, 3 to 5 inches, some quite porous and well bored with worms	34 "	116 "	
Black, sandy clay	1 "	117 "	
Fine sand, *water-bearing*	7 "	124 "	
Black, sandy clay	1 "	125 "	
Fine sand, *water-bearing*	3 "	128 "	
Dark, sandy clay, scattered layers of sandstone and shell rock, 3 to 5 inches thick	50 "	178 "	
Dark, sandy clay, changeable to more sandy; scattering layers of sandstone, shell and wood	128 "	306 "	Plastic clays.
Fine sand, some gravel, sand crusts, and floating brown clay lumps, *water*	8 "	314 "	

Red and white variegated clay...........	24 feet.	338 feet.	
Sand and sand-rock alternately, 5 inches to 2 feet thick, then clay veins and considerable wood........	18 "	356 "	
Fine sand at 367 feet..........................	3 "	370 "	
Coarse sand, *water, but not much*..........	17 "	387 "	
Coarse gravel....................................	3 "	390 "	
Fine sand..	5 "	395 "	
White clay..	5 "	400 "	
White sand and some coarse gravel....	10 "	410 "	
Fine, white sand...............................	22 "	432 "	
Dark sand, full of mica; looks like rotten rock.................................	8 "	440 "	
Pieces of stone clay........................	11 "	451 "	
Coarse, dark sand, mixed with red clay..	8 "	459 "	
Fine, white sand...............................	20 "	479 "	
Dark clay...	4 "	483 "	
White and red clay..........................	12 "	495 "	
Sand..	2 "	497 "	
Thin, white clay...............................	11 "	508 "	
Dark clay...	6 "	514 "	
Thin, white clay and a little gravel mixed with it...............................	2 "	516 "	Plastic clays.
White and red clay mixed..................	18 "	534 "	
Soft, light-colored clay.......................	4 "	538 "	
Alternation of tough, red and white clay..	12 "	550 "	
Dark clay...	25 "	575 "	
Sand..	13 "	588 "	
A little layer of sand, then coarse, white sand and some lumps of clay..	12 "	600 "	
Coarse sand and gravel.....................	3 "	603 "	
Fine sand..	13 "	619 "	
Clay..	6 "	625 "	
Same clay, with wood........................	11 "	636 "	
Mostly dark clay...............................	8 "	644 "	
Sand..	7 "	651 "	
White clay..	13 "	664 "	
Sand..	15 "	679 "	
White clay..	2 "	681 "	
Gravel and coarse sand.....................	9 "	690 "	
Red and white clay...........................	25 "	715 "	
Sand, in which the boring stopped.			

ARTESIAN WELL AT COLLINGSWOOD.

Record and specimens furnished by W. C. Barr.

Surface sand	8 feet.		
Marly clay, dark color	40 "	48 feet.	Clay marls.
Sandy clay, lighter color	23 "	71 "	
Gray sand	25 "	96 "	
Greenish marly clay, with sand and gravel mixed	9 "	105 "	
Same, lighter in color, with large, white pebbles, some large as walnuts, &c.; blue-gray gravel	20 "	125 "	
Whitish sand	16 "	141 "	
White clay streak	2 "	143 "	Plastic clays.
Red clay	27 "	170 "	
Reddish sand	14 "	184 "	
White clay	12 "	196 "	
Coarse, yellowish-white gravel, with large pebbles and *water*.			

N. & G. TAYLOR'S ARTESIAN WELL AT PHILADELPHIA.

In Cretaceous clays of the New Jersey series, underlying the south-eastern part of the city. Well bored and record furnished by C. G. Orcutt. Diameter, 12 inches.

Black muck (river alluvium)	27 feet.		Recent.
Coarse gravel	17 "	44 feet.	(Age?)
Yellow clay	1 "	45 "	New Jersey plastic clay series. Cretaceous.
Red clay	30 "	75 "	
Yellow clay	18 "	93 "	
Blue clay, mixed with yellow	10 "	103 "	
Coarse sand and gravel, mixed with a little clay and a few large cobbles; plenty of *water* in this	27 "	130 "	
Yellow clay	6 "	136 "	
Soft mica rock	29 "	165 "	
After this, hard rock, in which boring was continued to the depth of		670 "	

The water found in the heavy gravel at 130 feet, at the base of the soft strata, was cased off. The first water obtained in the rock was found at the depth of 400 feet. To increase the quantity the boring was continued to 670 feet. The yield is 250 gallons a minute.

There are a considerable number of wells in the southern part of Philadelphia, near the river front, that draw from the 130-feet horizon. One sugar-house has eight of them. This horizon is at the base of the Cretaceous plastic clays which cross the State of New Jersey from Amboy to Trenton, and then skirt the Delaware river to Pennsgrove, where they cross it and enter the State of Delaware, near New Castle. These clays have been met with in sinking wells at the last-named place.

ARTESIAN WELLS AT PAVONIA, AT THE PENNSYLVANIA RAILROAD COMPANY'S SHOPS.

The railroad company has for years been using water from three wells at this station, the wells being respectively 60, 67 and 82 feet deep. These wells are but a short distance from the Stockton Water Company's wells, but are upon somewhat higher ground. The railroad company, however, some years since, made an unsuccessful attempt to obtain water from a deeper well. The officials of the company presented a full set of the borings from this well, and, as it is deeper than any of the wells at either Pavonia or Stockton, its record is here inserted:

WELL NO. 2, PENNSYLVANIA RAILROAD COMPANY, AT PAVONIA.

Gravel	6 feet.	6 feet.	
White clay	10 "	16 "	Plastic clay series.
Sand	19 "	35 "	
Gravel, *water-bearing*	23 "	58 "	
Fine sand	22 "	80 "	
Red clay	5 "	85 "	
Fine sand	10 "	95 "	
Yellow clay	10 "	115 "	
Yellow sand	11 "	126 "	
Coarse sand	6 "	132 "	
Gravel	32 "	164 "	
Large pebbles	11 "	174 "	

An official of the railroad company writes: "The pressure from the bottom was very great and filled the pipe as fast as we could sand-pump. The desire was to bring the water as near the surface as possible. As we had one well, No. 1, giving good results at 82 feet, it was determined to abandon No. 2 and drill sufficient wells at the normal depth of 60 to 82 feet to give the required amount of

water, 275 gallons per minute. This amount has been furnished without interruption the past three and one-half years [now five years]. Dr. Dudley [the company's chemist] pronounced the water obtained a remarkable find and nearly organically pure. It is seldom we are called upon to wash out the wells. When we do, white sand and white gravel come to the surface."

The water from the wells of 60 to 82 feet depth probably represents the 64 to 78-feet horizon of the Stockton Water Company, in which, however, they have but one well. The abandoned well had probably reached the 121-feet horizon of the Stockton company, in which they have six wells. This horizon is probably the same as is drawn from by the wells in southern Philadelphia, and by a well at the Cooper Hospital, Camden, depth 129 feet; also by five of the Stockton wells. The wells at Pavonia and at Stockton, are upon nearly the same line of strike of the strata, which is northeast and southwest.

ARTESIAN WELLS AT STOCKTON.

At this point seven artesian wells have been put down by Kisner & Bennett, for the Stockton Water Company. From full information respecting each well, kindly furnished by Jacob H. Yocum, engineer in charge, the following condensed statement is made:

Well.	Depth.	Water rises—
No. 1.	68 feet.	Within 12 inches of the surface.
" 2.	116 "	" 18 " " "
" 3.	119 "	" 18 " " "
" 4.	124 "	" 8 feet 6 inches of the surface.
" 5.	130 "	" 13 feet of the surface.
" 6.	121 "	" 18 inches of the surface.
" 7.	117 "	" 18 " " "

Excepting well No. 1, they all draw from the same water stratum reached at the same level, the difference in depths being due to difference of elevation of the surface. There being a very close correspondence in the thickness and description of strata passed through by each well, the record of well No. 6, only, will be given, as it answers equally well for all.

Sand, *filled in*	5 feet.		
Marsh mud	8 "	13 feet.	Recent.
White clay	3 "	16 "	Plastic clay series.
Red clay	9 "	25 "	
White sand	20 "	45 "	
White clay	19 "	64 "	
White sand; *water horizon* of well No. 1	14 "	78 "	
Yellow clay	16 "	94 "	
Coarse sand and gravel; *water horizon* of wells No. 2 to No. 7	27 "	121 "	

In three of the wells upon the higher ground the marsh mud was absent, while the white clay noted beneath it had a thickness of eleven feet, instead of only three feet, its thinness in wells upon the lower ground being due to stream erosion. In all cases there was a covering of three to five feet of sand or earth.

Since the above was written a similar record has been furnished by the contractors, Kisner & Bennett.

The wells are arranged in two rows, and are all connected with a main running between the rows, all being pumped simultaneously through the main. J. H. Yocum writes, "In our test trial we found that we could depend upon an average of 125 gallons per minute from each well. The water is excellent, pure and soft."

ARTESIAN WELL NEAR BURLINGTON.

An artesian well was put down for Ezra Bowen, two miles east of Burlington. Orcutt Bros., the contractors, furnish the following record:

Soil	6 feet.		
Black mud or marl	53 "	59 feet.	Clay marls.
Green marl	44 "	103 "	
Gray sand, with wood; no water	17 "	120 "	
White clay	4 "	124 "	Plastic clays.
Red-mottled clay	21 "	145 "	
Dry, dark, lead-colored clay	5 "	150 "	
Sand and hard crusts	4 "	154 "	
Medium fine to coarse sand and gravel,		at 253 "	

SUMMARY.

Former reports of the Survey have demonstrated that below the lower marl there occur a series of clay marls, beneath which is a series of plastic clays.

Careful study of the wells in the second division of this paper shows that at the base of the clay marls and above the plastic clays there are beds of blue-gray coarse sands, and blue-gray, heavy, pebbly gravels, which yield water that will overflow about ten feet above tide-level.

About 100 feet below these, and that distance within whitish and pinkish clays resembling the plastic clays, are found exactly similar sands and gravels, with large pebbles and even cobbles, only the color is slightly different from the gravels above, being now a yellowish white, with sometimes a faint tinge of pink. These wells yield water that also rises about ten feet above tide.

In accordance with suggestions made to the author, it may be that the *blue-gray gravel* and the *yellowish-white gravel*, with their interbedded clays, may, either wholly or in part, represent a transition series between the clay marls and the plastic clays proper.

From the first-named horizon, the *blue-gray gravels*, wells at the following places draw their supply: Sewell, Wenonah* and Gloucester.* The well at Hartford was abandoned just above it.

The second-named horizon, the *yellowish-white gravels*, furnishes water to wells in southern Philadelphia and at the Cooper Hospital, Camden; also at Pavonia, Stockton, Jonathan Williams', near Moorestown, and Collingwood.

The wells noted at Columbus, Burlington and Mount Holly are stratigraphically much deeper and must find their supply from still lower water-producing sands.

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*These wells are being developed at this writing. Full details are not yet in hand, but sufficient is known to warrant the above statement.

PART V.

I.

Notes on the Sea-Dikes

OF THE

Netherlands.

II.

Reclamation

OF THE

Lowlands of the Netherlands.

I.

NOTES ON THE SEA-DIKES OF THE NETHERLANDS.

THE SEA-DIKE AT HELDER.

At Helder, in the Province of North Holland, where the waters of the Zuider Zee find an outlet between the mainland and the island of Texel, and where there is a strong current, the protection of the point or hook has made it necessary to build dikes and jetties of great strength, to resist the force of the waves and the scouring action of the current. There is a continuous dike around this point of the mainland from the dunes on the North Sea to the Zuider Zee. A part of the line is occupied by the fortification, and there the dike is of great strength and is, in fact, a part of the defensive works.

Along the sea front jetties are built at right angles to the shore-line and are about 500 feet apart. These jetties are of stone, with fascine mattrasses at the base, which are loaded with heavy blocks of granite. On the open sea-front, to the northwest, they are larger than on the side next the strait. The facing is of trap-rock, and the upper surface is slightly convex in cross-section. Their average length is 160 feet. The shore end is a little above high-water mark, descending to the level of high water at the other end. Notwithstanding the large size of the blocks of stone used in them, the severe storms sometimes tear up this facing and carry these blocks several rods upon the strand, so that repairs are often necessary.

The Helder dike has its seaward slope at a low angle, estimated to be less than 10°. It is faced with stone. The blocks of granite are five to six feet in length and are not dressed. They are laid close together and the interstices are set with smaller stone, so as to make a compact layer nearly two feet thick. In the more exposed points and at the northwest, on the sea front, fascine mattrasses were used at the

bottom, covered with heavy stone and faced with blocks of columnar trap-rock which are set vertically and nearly as close as cut stone. The stone facing extends up the slope to the top of the dike and is approximately 100 feet wide. On account of the strong current off this point the water is deep close in to the shore. According to Storm-Buysing, the depth of the water at 50 yards from the foot of the dike is about 100 feet. Heavy blocks of stone, making a massive rip-rap work, cover the steep slope this distance and down to this depth of water. The crown of the dike is 35 feet wide and 15 feet high above high water. It affords ample space for a roadway, whose bed is graveled, and for a foot-path or promenade, from which the traveler has a good view of the sea on the one hand and on the other looks down upon the streets of the town. The inner or landward slope is steep (about 1 to 1.25) and is grassed. The dike on the Nieuwe Diep, or new harbor, is wide and offers a commodious landing-place from the vessels which unload here.

THE SEA-DIKES AT PETTEN.

Petten is a small hamlet on the North sea and in the province of North Holland. It is ten miles north-northwest of Alkmaar. The dune hills which border the sea from Helder to Petten are here wanting and there is a gap of about three and a half miles (5,500 metres) in the coastal-dune belt at this place. South of Petten the sand hills attain a height of 150 feet in some points and a maximum breadth of three miles, opposite Bergen. The break or gap in the range rendered necessary the construction of sea-dikes to replace the sand hills which elsewhere serve as a natural barrier to the encroachment of the sea. There is a large area of reclaimed land in meadows (polders) in this province whose surface is several feet below the sea-level at low water, and the defenses at Petten form an important link in the chain or cordon surrounding this low-lying and fertile territory. The old maps of the district, 150 to 300 years old, show that the dune hills have suffered some changes in that time, although the defensive works antedate these maps. This is historic ground in the Netherlands system of sea-defenses, and the following notes on the history of the sea-defenses at Petten are taken from a statement by J. F. W. Conrad, member (council) of the Royal Institute of Engi-

neers, and published in the journal of that Institute in 1881.* He says: Of the dunes between Camp and Petten there is mention made in the first half of the fifteenth century. Prior to 1505 the defenses against the sea consisted of the unprotected beach, with a line of dunes lying back of it, planted with dune-grass or helm (*Arundo arenaria*), to prevent the drifting of the sand and the formation of breaches in the sand reef or barrier. These dunes were constantly being impaired by the action of the storm tides and moved landward.

In 1506 a beginning was made of artificial defenses against the sea. Jetties and piles were set, and the system heretofore followed of retiring before the sea was abandoned. Meantime an inner or "sleeper" dike was built in 1528.

The artificial device of a sea-dike was not neglected, and in 1547 no less than twenty-two jetties had been projected before Petten and Hondsbossche. After that year there was an interval of neglect, and in consequence the Hondsbossche dike was broken through in 1570, and an inner dike, laid out in 1571, had to serve as a defense.

At the beginning of the seventeenth century the Hondsbossche dike was considered unsafe, consisting of nothing but an unprotected beach and a mound of sand lying back of it. Throughout the seventeenth and eighteenth centuries no protective measures were taken for the beach and sea-dike, and safety was sought in the construction of successive inner dikes. This state of things continued until 1794, when finally, on the advice of Inspector-General Brunings, a beginning was made in the systematic construction of jetties upon the beach.

Between 1839 and 1847 a line of contiguous piles was driven in the sand at the shore end of the jetties which had been repaired. This pile defense was greatly injured in the storms of December, 1862, and December, 1863, and the dike of sand behind it was in danger of being broken through.

It was not until 1872 that the scientific system of defenses of the Hondsbossche sea-dike was begun. They were largely constructed in the years 1872–1877 by aid of subsidies to the amount of about $900,000 (two and one-fourth million guilders) from the general government and the provincial government of North Holland. The twenty-nine jetties were reconstructed and repaired. The protection

* Tidschrift van het Koninklijk Instituut van Ingenieurs, 1881, 1882.

by means of jetties was opposed to the original plan of the Hondsbossche improvement, as they were considered to be injurious rather than protective, but they were ordered by the government authorities, both general and provincial, by whom the subsidies were furnished for the work.

The Petten and Hondsbossche dikes are essentially one, but are separate in ownership and in control. The former is 4,000 feet long (945 metres) and the latter 14,760 feet (4,500 metres). Both of them are under the supervision of the officers of the Rijks Waterstaat, a government bureau which has charge of the dikes, canals and waterways of the kingdom.

The protective measures here employed are jetties and sea-dikes. The jetties are placed at right angles to the shore line and are 100 to 300 yards apart. They serve to check the velocity of the current along the shore and arrest the movement of the sands, and thereby prevent the undermining action of the waves and currents on the foot of the dike. There are nine jetties in front of the Petten dike, twenty-nine in front of the Hondsbossche and eleven north of the latter for the protection of the beach and the dune; in all forty-nine jetties, within a shore length of six and a half miles. Those in front of the Hondsbossche dike are from 300 to 450 feet long, besides 60 to 80 feet of rip-rap (stort-werk) at the sea end. Before the Petten dike their length is 380 feet, of which 300 feet is course work. The jetties to the north of the dikes and in front of the dune are 540 to 740 feet in length, of which about 80 feet is rip-rap. The height at the shore end is one and a half feet and at the sea end 4.9 feet below high-water mark or the Amsterdam datum plane (A. P.) The distance between the jetties in front of the dike ranges from 370 to 410 feet, and in front of the dune from 360 to 940 feet.

The construction is shown in detail in the accompanying sections and plans.* The dikes are shown in vertical cross-section, the jetty in plan and also in cross-section. (See Plate VIII.)

In constructing the jetties, fascine mattrasses, made of small brush and young tree stems or poles, are first sunk upon the surface of the ground at the sea end by a load of stone. For this mattrass-work brush of various kinds of wood is used. Willow and alder are common. They are woven, as it were, together and tied in the several

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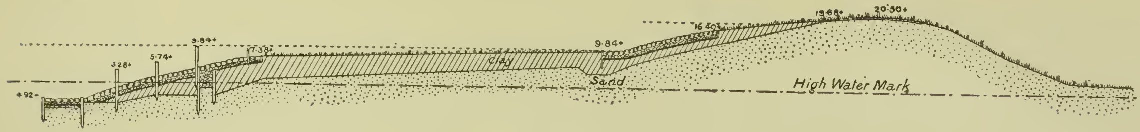
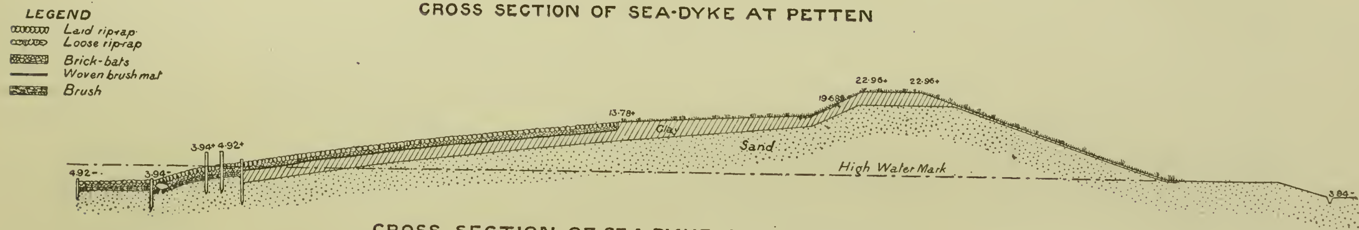
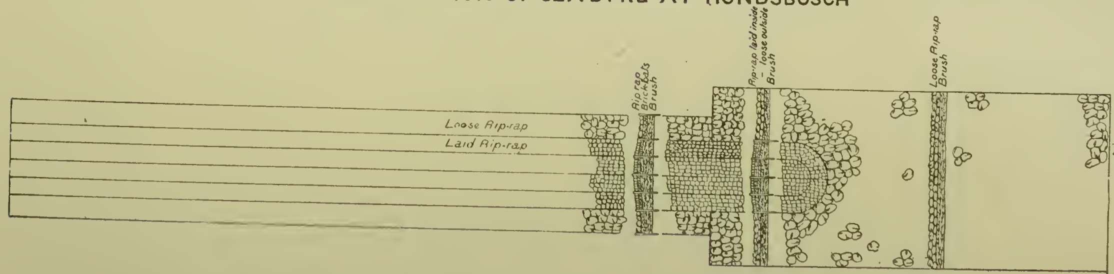
*These sections, with explanatory notes, were kindly furnished by M. H. A. Straater, superintendent at Petten for the Rijks Waterstaat



CROSS SECTION OF SEA-DYKE AT PETTEN



CROSS SECTION OF SEA-DYKE AT HONDSBOSCH



PLAN AND CROSS SECTION OF JETTY AT PETTEN DYKE

PLATE VIII.

layers by cross bundles or withes. The average thickness is about three feet. They are covered by heavy stone, laid closely together, and they serve as a protection to the jetty against the scouring action of the currents along the shore. The jetty proper consists of the brush layer or fascine mattrass at the bottom, covered by a layer of clinker or broken brick and capped by set stonework. The top is slightly convex, as shown in the cross-section in the illustration. (See Plate VIII.)

The stone used here is from Tournay (known as Doornik stone) and it is set close, with the interstices rammed with the spalls and small stone, so as to make a compact facing or revetment. Rows of piles are set lengthwise the jetty, sunk through the stonework and the mattrass layer into the bottom-sand of the beach, and serve as cribwork to hold the mass in position. Seven rows of such piles are shown in the plan and sections. The average cost of one of these jetties is 10,000 to 15,000 guilders, or about $4,000 to $6,000.

The dikes also have fascine-mattrass layers at the sea-bottom which are loaded with stone rip-rap, or brushwork covered with clinker and that with rip-rap. In the Hondsbossche dike the fascine-work with clinker and rip-rap is shown in the vertical cross-section. There is at the foot what is termed a "plas-berm," or splash-bench, about 10 feet wide and at a depth, at foot, of 1.50 metres and of 1.20 metres at the upper side. This consists of stone set on clinker with the brush-work at bottom and with rows of piles on the sides. From 1.20 metres below high-water mark to 0.40 metres above the same datum plane the brushwork is covered with clinker and the surface is course work in stone (basalt). This section of the dike is 24.5 feet wide. In it there are two rows of piles, which serve to break the force of the waves. Above this there is a layer of basalt rock laid flatwise upon a brick floor laid on clay and having an inclination of 7 to 1, and higher up, 9 to 1. The breadth of this section is about 120 feet, and its upper side is 13.5 feet above the high-water plane. The stone-faced section is succeeded by a grass-covered bench, 78 feet wide, slightly sloping from the stone-faced section upward to a height of 16.5 feet. Its slope is 20 to 1. For a breadth of about eight feet along the upper side of the basalt section the surface of this bench is set with stone. The dike above this bench consists of sand, covered with a layer of clay, and having an inclination in its outer slope of 2 to 1 up to a height of 23 feet above high-water mark, and which is

faced with brick to a height of 20 feet. The crown of the dike is 16.5 feet wide and has an inner slope of 3 to 1.

The part of the Hondsbossche dike adjacent to the Petten dike differs in construction from the rest. It has an outward slope of 6 and $7\frac{1}{2}$ to 1, is covered with a facing of columnar basalt, has no rows of piles or "wave-breakers," but has an outer bench rising to a height of 20 feet, and its crown has a breadth of 23 feet.

The Petten sea-dike differs from the Hondsbossche in some of the details of construction. The work was done mainly in 1867 and 1868, and with a view to the retention of the original features of the dike so far as it was possible to keep them. It has a splash-bench, not, however, as wide as that of the Hondsbossche, which is succeeded by a stone-faced slope, convex in section, and is set with three rows of piles. This slope extends to a height of seven feet above high water. The outer bench is wider than in the Hondsbossche dike and has a slight inclination. The stone facing is carried up the slope above this bench to a height of 17 feet. The crown is 26 feet wide, and the inward slope descends at an angle of 2–8 to 1. It may be observed that the form is such that the onset of the wave is opposed more in the front of the Petten than in that of the Hondsbossche dike. The latter presents a more nearly uniform slope toward the sea. In the Petten dike there is the stone-faced upper section above the beach, which offers stout defense in case the outer works are damaged seriously.

Since the completion of the Hondsbossche dike the storm waves have been noted once as high as 5.25 feet above ordinary flood mark, and they ran then to a height of 13.5 feet above the same datum, and as far as the slightly-inclined surface of the outer slope. One wave reached to a height of 19.5 feet and to the crown of the dike, which has since that time been raised. During ordinary storm tides the water rises to a vertical height of 2.5 to 5.5 feet higher on the Hondsbossche than it does on the Petten dike, and to a point where the dike cross-section is from 23 to 46 feet wide. Experience has shown that the accession to the beach has been notable since the building of the jetties. It remains, however, to be proven how far these defenses are able to resist long-continued high storm tides, such as occurred in December, 1862, when the water rose to a height of 8 feet above mean flood, and in December, 1863, when the height was nearly 10 feet and when the water was driven by a gale of 300 pounds pressure for two consecutive hours upon the dike.

THE WEST KAPPELLE SEA-DIKE.

This dike is at the most exposed point on the North sea coast of the Netherlands and is most noteworthy among the sea-defenses of that country. The island of Walcheren, in the province of Zeeland, is one of the richest agricultural districts in Holland, and its fertility is largely owing to its rich sea-clay soil. A large part of it is below the ocean level and it is inclosed by dune hills and by strong dikes. The dunes on the North sea coast are massive natural ramparts which protect it against the encroachment of the sea, and they are guarded with the most jealous care. There is a line of jetties from Flushing, on the south side, past West Kappelle to the mouth of the Scheldt, on the northwest, for the protection of the dune barrier. The range of dune hills is narrow—in many places a single row of hillocks of sand—but high, reaching a height of 50 to 100 feet between Domburg and Flushing. Hence the great care which is taken to maintain this barrier of sand hills. At West Kappelle, eight miles west-northwest of the old city of Middleburgh, and the westernmost point of the island, the encroachment of the sea and the destruction of the dune barrier made it necessary to resort to artificial measures and the construction of a sea-dike of great strength to resist the waves, which break with great force on this exposed point. The full sweep of the wind from the northwest to the southwest quarters over the North sea forces the water with heavy breakers on this point, so much so that the foam of the wave crests often glides over the crown of the dike, and stone of two tons in weight are carried twelve to sixteen rods up on its outer slope. The earliest known dike here was somewhat farther to the west than the present one—that is, seaward—and the old church tower, near the dike, was in the center of the village. The church has disappeared and the high tower answers the important use as a light-house on this westernmost point of the island. Some of the work of the older dike was done as early as 1470. Its authentic history dates back to 1540.

The water off the point is deep—50 to 75 feet—in a northwesterly direction and not far from the shore. The rise and fall of the tides is about eleven feet, and the high-water mark is 2.07 metres above the Amsterdam datum plane (A. P.) The core of the dike is sand, and is, in fact, a sand-ridge formed into shape and protected against the

eroding action of the waves by its covering of clay, straw matting and stone facing. In cross-section the outer slope is polygonal-convex, as shown in the accompanying illustrations (Plate IX.) The crown of the dike at the south end is 19 feet above high-water level and about 22 feet at the north end. The rip-rap at the foot is thrown upon fascine mattrasses, made of reeds, and about a foot and a half thick, which accommodate themselves to the inequalities of the sea-floor and prevent scouring by the undercurrents. The sand core is covered to a depth of three feet, increasing a little near the top, with a clay found in the vicinity. On this clay is a layer of brick, and the stone facing is set on the brick. Its seaward or outer slope is in sections, and is steepest near the foot, ranging from 6½ to 1 at the south end, and 7–9 to 1 at the north end, down to 12 to 13½ to 1, and thence to 18 to 1, near the top. It is protected according to situation, and from low-water level to 8 to 13 feet above the same datum plane, by a revetment of stone and by piles and a straw-mat covering. The rip-rap at the foot consists of heavy blocks of stone, and it occupies a belt from 4½ feet below to 2.8 feet above the Amsterdam datum plane. There is at the foot of the dike a row of piles, near low-water mark, which serves to hold the stone coursework in place. Basalt, a hard and durable stone, and columnar in structure, which is obtained from the Rhine district in Germany, is used as facing material for the lowest section of the outer slope. The pentagonal and hexagonal blocks are fitted close together in a compact layer about a foot thick. They are laid on side—that is, on the columnar faces. It is preferred to the Tournay limestone, which has a tendency to split along the bedding-planes, as it is laid on edge. Much of the latter kind of stone has, however, been used here, as it is less costly than the basalt. Sandstone from Vilvoord, in Brabant, also is used. This section or belt has a mean breadth of 60 feet. Next above it there is a section of basalt stone facing, which is narrow, only about twelve feet wide and is nearly three feet above high-water level. Following the basalt section, and extending from 8 to 13 feet above high-water mark, there is what is known as the "krammat" covering, a matting which is made of bundles of coarse reeds, laid at right angles across one another and fastened at the intersection points by pins driven in the earth. This covering costs about ten cents a square yard. It holds the surface against the swash of the waves as they run up the slope and return, at extraordinarily high tides, and where grass will not

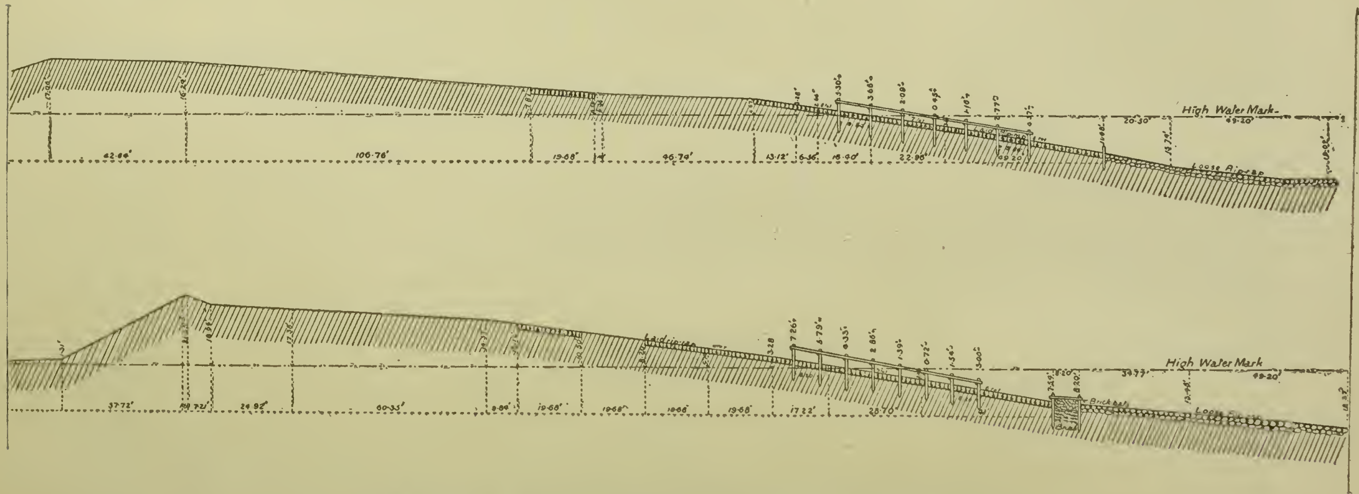


PLATE IX.—Cross Section of Sea-Dyke at West Kappelle.

grow. It is not very durable, but on account of cheapness is replaced at short periods. The grassy bench or berm is next above the straw-mat section, and then the crown of the dike. The inclination of the higher part of the outer slope is 18 to 1. In places above the straw-mat section there is stone facing for a breadth of five yards. The total breadth of the dike at the level of low water is 360 feet, and at high water about 300 feet.

For the more effectual protection of the stone-work and to break the force of the waves, there is near the foot of the dike, a narrow belt of *stake-work* (staket-werk of the Dutch). At West Kappelle the length of this stake-work is about 1,000 yards, and it is from 4 to 14 feet wide. The stakes or piles are set in rows lengthwise the shore and the dike, 1½ to 2 feet apart, and in the stone facing. There are from 6 to 12 parallel rows. They are of oak or of fir (which is creosoted), and are 11½ feet long and 10 to 12 inches thick at top, sharpened at the bottom, and are set so that they are 3 to 5 feet above the stone facing of the dike. In some cases they are fastened together in a kind of cribwork by timbers lengthwise and crosswise, bolted to the tops of the stakes. Through openings at intervals, which run obliquely down the slope, access is had easily to and through them. This stake-work is just where the most exposed sections require it. At less exposed points the stakes stand singly and in rows, without the waling tie-pieces. It is often damaged by storm tides and waves, and frequent repairs are required.

The crown of the dike is about 40 feet broad, affording room for an excellent roadway and a service railway line, but no trees are planted on it. There is also a light-house on it. The water in severe storms runs to the top of the dike in foaming sheets and in spray of the breakers, but not to do any material damage.

The dike is itself protected as a part of the coastal-dune range by the system of jetties referred to above; and there are thirty-seven of them in front of the dike, at distances of one hundred to two hundred and fifty yards apart. They stretch out at right angles to the shore. In their construction the fascine-mattrass layer is first made, and it extends somewhat beyond the jetty on both sides and at the sea end. Heavy blocks of granite (stort-werk) are thrown upon this mattrass, which protect the jetty's cribwork against the bottom currents and serve to hold the sand in place. Five rows of piles are driven in rows lengthwise the jetties and rising about one-third of their length

above low-water mark. The piles are from six to eight inches apart in these rows. These piles, here as elsewhere in Holland, have to be protected against the borer (*Teredo navilis*) by a sheathing of broad-headed nails which are driven into the parts of the piles wherever the wood is exposed continuously to the water. They prevent in part only the ravaging effect of this little marine borer. The upper surface of the jetty consists of large blocks of stone set compactly together, forming a slightly-arched, cross-vertical section. One row of piles is set on each side and the remaining three at equal spaces apart, running longitudinally through the mass of the jetty from shore end to the sea end. Cross pieces serve to hold the piles together in a sort of cribwork and give strength to the whole structure. The jetties slope at a gentle angle seaward.

When it is noted that in December, 1862, the high water rose to twelve and a half feet (3.82 metres) above the Amsterdam mark, or five and a half feet (1.75 metres) above mean high-water level, the danger at this locality may be appreciated, particularly when the exposed position to the sweep of the winds over the North sea is taken into consideration. The cost of maintenance is heavy on account of repairs every year, but the aggregate value of the property whose protection is secured by this dike makes it imperative to keep the line of protection intact. One authority places this cost of maintenance in Zeeland at $250,000 (600,000 guilders) a year, and says that there are in the provinces 1,000,000 square metres of fascine-work and 1,200,000 square metres of stone pitching. In the case of the West Kappelle dike the cost all falls upon the island of Walcheren, and it imposes a comparatively heavy tax.

FLUSHING.

At Flushing, on the south side of the island of Walcheren, province of Zeeland, the harbor is formed by massive dikes, as well as a part of the fortifications west of the town. The harbor is, as it were, walled in by them. They are remarkable for their strength and for the care taken in their construction to fit them as roadways and avenues of communication between the town streets and the harbor. The fascine-mattrass layer is at the base, extending across nearly the whole breadth of the dike, and it is loaded with stone. This style of construction is in general use where roadways occupy the crown of

the dike and where the ground is not solid. The main body of the dike is sand, which has for protection, on its outer slope, a layer of tough clay, and that in turn covered with a layer of red brick, which holds the clay and makes a solid bed for the outer facing of stone. Basalt is used for this purpose.

Jetties are employed to protect the outer sea-dike at Flushing, but they are maintained with difficulty on account of the scouring action of the current in the Scheldt and the deep water with narrow foreshore. In places where there is less of this scouring action of the current along the shore the sand accumulates quickly and some of the jetties are nearly buried in it.

On the north shore of the island of Noord Beveland, in this province, and along the Oost Scheldt the scour is so great and the current so strong that the dike's front has not been maintained and some land has been lost. The newer dikes have been built behind the older ones.

From the descriptions as given in the preceding section it will be at once plain that the sea-dikes of Holland are expensive constructions, and their maintenance also is, of necessity, costly and such as to require governmental supervision.

The protection of so large tracts of country lying below the sea-level makes it necessary to build strong dikes and keep them in repair, to insure the safety of the inhabitants as well as the crops and constructions of a settled farming country. Towns and cities at these low levels are also to be guarded against the inroads of the sea. The water must be kept out of these low-lying lands as well as from doing damage to dikes which protect the parts of the country which are near or slightly above the level of the ocean. The range of sand hills or dunes of the coast serve as a barrier reef against the ocean waters, and make a line of outer defense. The sea-dikes which have been described in this report fill the gaps in the range of sand hills, and make a nearly continuous sea-front. There are interior lines of dikes also, and those which border the rivers and the inland waters, as the Zuider Zee.

New Jersey has practically no part of its territory lower than sea-level. The exceptions are the small areas of embanked meadows which have settled a few inches below mean-tide level. Until our tide-marsh lands have been reclaimed and made into farms and

market-gardens there cannot be any necessity for dikes of much size or strength. The conditions are at present not comparable with those of Holland. But for the protection of the ocean front at exposed points, where there is much wear of the shore and a gradual encroachment by the sea, the sea-dikes of Holland are good examples of successful protective constructions, and the study of the Dutch methods is suggestive of what we may do where like conditions exist. At Long Branch the wear of the bluff has been extensive and has destroyed the former beauty of the elevated promenade and roadway which ran in front of the hotels and cottages. And the encroachments of the waves in severe storms within the last two years have been such as to cut into the roadway and threaten some of the buildings nearest the margin of the bluff. The loss of land for the past half century has been variously stated. It is well known that the site of the former roadway is now in the water, and the distance from some of the older houses to the sea is much less than it was years ago. The value of the strip taken by the ocean would be great enough to-day to warrant adequate measures of protection. The property now threatened is valuable. It should be stated here that this locality is the sole one from Sandy Hook to Cape May where the hard ground meets the water of the ocean. The coastal line of dunes everywhere else borders the ocean and protects the mainland. Hence it would seem eminently proper for the State to consider the question of protecting this unique ocean front and beautiful bluff, and also the more practical one of saving its territory from destruction.

The study of the construction of the sea-dikes of Holland is therefore of practical importance in a consideration of the methods applicable to the Long Branch bluff. The West Kappelle and the Petten dikes are at points exposed to the direct force of the waves of the sea, but, judging from the greater breadth of the foreshore and the more gentle slope of the ground and the less depth of water at these places than at Long Branch, it would seem reasonable to assume that the action of the waves at the latter place would be more energetic and more destructive than they are on the Dutch coast.

The exposure at Long Branch is toward the ocean, and faces that quarter from which the more stormy winds blow and help to raise the water into high waves. The depth of the water, also, is such that it increases rapidly from the land seaward, which facilitates the movement of deep water directly against the land. The off-shore

currents which strike obliquely, help to cut away the sands and clays in the foreshore and undermine the gravelly-sandy bluff, and also carry away the materials brought down to the strand from the bluff. The protective measures which may be considered as available at this place must have reference to these more exacting conditions of exposure in order to be at all effective. The jetties and bulkheads which have been built are examples of what may be done to arrest temporarily the onward movement of the sea upon the land, and to put away further the ultimate fate of the bluff. They have answered their purpose as such temporary measures of protection, at comparatively slight cost to individual owners and some associated proprietors. For a proper system of sea-defense there is need, first, of complete organization and a careful study of methods, preparatory to the adoption of a comprehensive plan, which shall include all of the property interests and the State, in so far as it is the custodian of its public interests and the servant of the people in protecting them. Some modification of the form of dikes used by the Dutch is necessary for the conditions at Long Branch. There a sand hill is to be made into a dike; here a bluff, high enough itself for a dike, is to be protected. There the water is more shallow and the strand breadth is greater; here deeper water and a narrow strand are the elements to be considered. The differing conditions due to cheaper labor and consequently cheaper materials are also factors in the case. The essential features of the sea-dikes, at the localities in Holland here referred to, are the gentle slope of the outer front of the dike and the strength of the facing. The dike has the form which offers less resistance than a wooden bulkhead, and its facing of stone resists the wearing action of the waves and also affords a more easy return of the water to the sea. The water is allowed to run up the gently-sloping surface, after being broken up and in part arrested by the rows of stakes or piling set in the foot of the dike, and then to expend its force thereon and run rapidly back to the sea again.

At Long Branch the bluff may be so worked over as to make a dike. For this purpose it would be necessary to cut it down into benches or terraces, with sloping sections between them, which should be faced with stone. Of course the construction, like that of West Kappelle, would involve the cutting back of the top a long distance, and would use all of the remaining strip of land between the houses and the sea. A steeper slope might be as effective and less expensive.

It could be in two sections and separated by a bench or terrace about half the height of the present bluff. In form, the outer surface would be preferably convex, for greater strength and for economy in construction. The bench would be a promenade-way for pedestrians in pleasant weather. The top of the bluff should be raised so as to make a broad crown, on which there might be a fine drive-way, as well as walks. These very general suggestions show what may be done in the use of a modified form of the Dutch sea-dike, consistent with existing conditions and which, it is believed, would make the bluff more attractive and more beautiful than it is now, and save from further encroachments of the sea.

The alteration of the shape of the bluff, as here pointed out, would not alone be effective. Jetties certainly would be needed to check the flow of the currents of water, which cut away the strand as well as bluff. Their usefulness has been seen in what have been built to protect the front along the West End and Howland properties, and the extension of the jetty system northward along the whole front is an evidence of their value. The bulkheads, however, show that they alone are insufficient to protect. With jetties and a new-formed and stone-faced section of the bluff, in place of the unsightly and wooden bulkheads, the transformation would be pleasing to the eye, useful to the owners, conducive to the greater pleasure of the increasing crowd of summer visitors, effective in stopping the wear of the bluff, and save from destruction to the State its one point where the hard ground comes boldly to meet the sea.

The use of dikes for the protection of the shore at other points along the coast may be a subject for future consideration, particularly where valuable water-fronts are threatened by the wear of the land. At some of the new towns on the sand beaches the damage from waves in storms is great, and the loss of property is sometimes large enough to warrant the outlay necessary for jetties and low dikes. The construction of great dikes like those of the Netherlands is not practicable, but a smaller form, having less breadth and less height, is apparently within the limit of economy and entirely strong enough to meet the demands of the case at nearly all of the localities where they are needed at all. For it is to be remembered in this connection that the water off the coast is generally shallow and the strand is wide, affording conditions where the force of the waves is not so great as it is at Long Branch, and where the necessity for formidable

dikes does not come in to exaggerate the cost of construction. In fact, the destructive agencies on this line of sand beaches are the currents, which strike obliquely, or which run along shore, carrying away the sand from the gently-sloping sea-floor and the strand. The jetty has a more important work here than the dike—to stop these currents and their scouring action—and with jetties the dike may be low and broad.

The element of expense in the construction of sea-dikes is not so much in the earthwork as in the stone or brick facing. The core may be of sand, which is at hand; the earth or clay covering is to be had on the mainland and not far distant, generally; but the stonework is expensive on account of the cost of transportation, as there is no outcrop or quarry of suitable material in the southern part of the State, except the brown sandstone, which is found in comparatively few localities, in thin beds, and of limited extent. By water, stone can be had from the Hudson river or from New England quarries.

II.

THE RECLAMATION OF THE LOWLANDS OF THE NETHERLANDS.

The names of the country of the Dutch—De Nederlande, Netherlands, Holland or Hollowland, the Low Countries—all point to the fact of low-lying and consequently wet lands. The reclamation of this territory from the sea has given to this people a large part of their fertile country and made the Netherlands one of the richest in Europe. The improvement of the soil, thus won from the water, by the best methods of cultivation known to agriculture, has been so great that the low-lying parts of the Netherlands are all either rich meadows for pasture, or market-gardens for producing vegetables and fruit for the cities, also within the original domain of the sea. The skillful engineering, persistent and unwavering labor and watchfulness, and the expenditure of large sums of money through centuries, have made a wonderfully rich agricultural country where tide-marshes, sand-flats and wet swamps once stretched over a wide belt from the low, upland sand hills to the higher wind-raised dunes of the coast. The transformation of a district naturally desolate and almost worthless to agriculture has been looked upon as an object lesson to the world, showing what may be done where a wise economy of natural resources is had and where there is the patient industry and unflagging energy to wait for and to reap the results of far-reaching plans for improvement of the natural conditions. Environment has no doubt had its influence upon the people, and the reclamation of wet lands and of lakes and tidal estuaries and stretches of the sea has become, as it were, a business almost peculiar to the Dutch. One successful enterprise has led to another, until the territory has increased over one-third beyond its original area. And to-day the draining of a large part of the Zuider Zee, or so much as may be available

as farm land, is planned and is likely to become a fact within a few years. What has been done in the Netherlands is possible in our country, wherever the conditions are favorable and the results promising of profitable returns for the investment of capital. The ability to organize and to execute, as well as the means for doing the work are here. It may be possible that our people are too eager for results, and consequently are unfitted or unwilling to wait for the slow returns of income from investments put in the drainage and improvement of farm lands on a large scale where organized effort is necessary for the work. The conditions here are not so unlike those of the Netherlands that the example of the Dutch may not be instructive and suggestive of success. Because of the similarity of conditions and the promise of valuable results, some study as to the methods used by them seems to be desirable, and for it the following notes have been taken from a recently-published Dutch work entitled "Nederland als Polderland," by Dr. A. A. Beekman, an engineer and professor in a technological school at Zutphen, and more recently at Delft.* These notes are in part a translation of the work and partly abridged generalization of the same.

He notes the original constitution of the surface of the country as it was in early historic times; the rivers and their basins; the formation of the soil or bottom-lands along these streams and at their mouths; the origin of the deltas and of the sand-banks and sand dunes; the artificial drainage and its methods; the rainfall and the evaporation from the soil; and the regulation of the waters by administrative bodies. Following these chapters there is a review of the general topographic divisions of the Netherlands, and appendices containing notes of artificial inundations and the system of military defense by means of the sea.

FORMATION OF THE SURFACE.

The surface formations of the Netherlands are nearly all either alluvial or diluvial, belonging, therefore, to the later geologic periods. The latter constitutes 41 per cent. of the total area and the eastern part of the kingdom. It is overlain in the western part by the more recent river and sea deposits, which are here classed as alluvial or alluvium. It consists almost wholly of sand, gravel and cobble-

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* Nederland als Polderland, Zutfen, 1884.

stones, and is in part of Scandinavian origin. The source of a part of it may be referred to eastern and southern Germany. The sands are sometimes styled the loess deposits.

The fen-lands upon the sands, gravels, &c., have a black, peaty surface and extend over large areas. In them the peaty beds are twelve to fifteen feet thick in some cases. This deposit has been formed by the partial decomposition of aquatic vegetation in wet places or badly-drained localities. The so-called high fens are those upon higher grounds, which have originated in the growth and decay of such plants in woodlands, and where the fallen wood has been added to the peaty layer. When drained, such land sinks considerably. The marsh fens are the accumulation of more exclusively vegetable matter from the growth of plants in lower grounds and in the still or stagnant waters, and in the open country.

From many circumstances it would appear that ages ago the western part of the Netherlands was a kind of inland sea, similar in origin to the so-called "*haffs*" of the Baltic coast of Germany. This "haff" embraced what is now a part of Flanders, Zeeland, Holland, the present Zuider Zee and the low lands of Friesland and of Groningen, and it received the inflowing rivers Schelde, Meuse, Rhine, Ems, Weser and Elbe. It is possible to trace the boundary of this sea and note its depth, in the occurrence of fossil shells, which are found at depths of fifteen to twenty feet below the level of the ordinary flood tides. The sands of the old sea-bottom rest upon the older diluvial or drift beds, also of sand. A layer of clay deposited upon the sea-bottom made the fertile soils of the province of Holland, found in many of its drained lake basins, and the sea-clay beds are the nuclei of the islands of Zeeland and of South Holland, as well as of North Holland and parts of Friesland and Groningen. And it seems as if they were formed in the same manner as the sea-clay bottoms are to-day reclaimed in these provinces.

The great difference between the levels of low tide and of high tide in Zeeland occasioned a thicker deposit of clay, and hence the greater value of the famous clay lands of that province. Where the difference in height between low and high tide was less the clay was not as thick, and here and there the sand bottom was left exposed, and hence a surface less valuable or less fertile when reclaimed. These sea-lands, called "sea-polders," were among the first to be reclaimed or *impoldered*. In Zeeland they date probably from the

twelfth century.* Thus Zeeland and South Holland were originally composed of groups of islands which have been gradually joined by diking in the intermediate waterways and sea. Walcheren was made up of ten islands originally. The older map shows these islands, and the large map of the Waterstaat shows the accretions of land thus made by man.

In these districts where the waters were comparatively quiet there were the accumulations from the growth of water plants, at the level of the waters, and what are known as low fens were there formed. In some places mud was deposited upon these fens, as can be seen in the wide strip along the great rivers and waterways, and in the alternating layers of clay and peat. These alluvial lands along the rivers are known as the river-clay in the geological classification of the surface, and constitute wide belts of fertile soil between the Rhine and the Maas, the Maas and the Vaal, and elsewhere near the rivers. There are patches of coarse gravel and of sand and gravel also, brought down by the rivers ages ago, and which are now under cultivation, but generally the gravel and sand are found covered by clay to the depth of three to six feet.

If, as to the low-lying alluvial and diluvial lands, account be taken of the sand of the coastal belt of dune hills, which has been thrown up by the sea, it is easy to appreciate, as Staring says, that the expression "the Netherlands has won its land from the sea" must be taken as a poetic outburst, which puts a part for the whole.

POLDERS AND LAKE-BASINS (DROOGMAKERYEN); THEIR ORIGIN AND APPEARANCE.

As early as the times of the Romans dikes were constructed, but they were used by the Romans themselves mainly as means of communication. The land, whose uppermost deposits were not as yet artificially drained, must have been about on a level with ordinary high water, both in the low fens and in the alluvial sea-clay lands. At higher tides it was overflowed. Only the higher diluvial grounds and the dunes and the *geest-lands* were inhabited, and thence the hunter and the fisherman ventured forth into the fen-lands, covered with high forests and low underbrush, traversed and studded with numberless pools and lakes; and the keeper of cattle ventured, par-

* W. C. H. Staring; "Voormaals en Thans," p. 152.

ticularly in the summer time, upon the sea-clay lands, covered with reeds and grass, and herded his cattle upon the driest places, which, by the aid of the cattle, became a few feet higher, growing to "terpen," or knolls, even as they may be found to this day in Groningen and Friesland and on the Zeeland islands. The forests upon the fens were in part felled. The sea-clay lands, when their great fertility became known, the inhabitants learned to cultivate upon artificially-constructed elevations, and along the borders a few villages and towns arose. In the times of the counts, the earliest of them, who owned a little territory, began to encourage the diking of certain areas. Without the least concert of action and exclusively to serve private and local interests in so far as the land became more thickly populated, certain portions were gradually surrounded with dikes to protect them against inundations by the waters outside, in connection with which many disputes must have arisen.

The first dikes were overflowed by extraordinarily high tides and were often broken down. Those who constructed them remained owners of them and obtained rights in the lands protected, but they were required to keep the dikes themselves in repair. Thus originated the dike rights, which the count alone could bestow, while he always retained the highest jurisdiction *in re* the dikes for himself, even when subsequently special officials were appointed charged with the supervision of the dikes. Before the eleventh century there were probably no dikes or dams except in West Friesland (now North Holland), which fact is derived from this circumstance, that before this time not a single name occurs there of a place ending in *dyke* or *dam*.

In Holland, Count William Second and Floris the Fifth were the first to institute numerous and effective measures in the interest of dikes and the *waterstaat* in general. The more important dikes along the great rivers, for the purpose of holding back the waters of the latter, came into existence possibly between 1200 and 1400, although not as yet on the scale of the present ones.

There was no united action in the construction of dikes until the great water associations or water commissions (waterschappen) were formed—that is, associations of landed proprietors, with common interests regarding protection against outside waters, the removal of the inside waters, &c. As the government of the country grew in strength more associations were formed and received great powers,

even to the privilege of judicial punishment in case of the transgression of the regulations of the *waterschappen*, &c., and in general the government concerned itself more with the *waterstaat*. In Holland, probably Woerden and the Zwyndrecht Waard are the most ancient *waterschappen*. They date back to the early part of the fourteenth century. Within the principal dikes for holding back the outside waters the fen-lands (those covered with river deposits) were surrounded in part with dikes in the course of the fourteenth, still more in the fifteenth, and particularly in the sixteenth century. This shutting off of the river-waters was done in order to control completely the waters within the limits set off. The dikes prevented the access of water from without, while its exclusion made it possible to remove the water behind them. At first the latter work was done very imperfectly, but with the improvement of the wind-mill its accomplishment was more satisfactory. When the diked fen-lands were freed from the waters which fell upon them and the water was kept, as far as possible, a few inches below the surface of the ground, the spongy soil, which before held great quantities of water, settled to a considerable extent. In this manner all the fen-lands and those along the old river channels, and which were covered with a more or less heavy layer of river deposit, were gradually surrounded in contiguous sections with dikes. They thus became *polders*, and their surfaces sank to levels from the Amsterdam datum to about two metres, or more than six feet, below that datum-plane.

Most of the polders originated probably after 1600. At that period the water-defenses along the great rivers and the sea were already quite capable of controlling these under ordinary circumstances, but at that time it was still necessary, in order to keep the country within the great dikes drained, to shut this off in sections, and where it did not adjoin the higher levels of the dune areas, by means of supplementary inner dikes.

The fen-polders formed in this way are so low, on account of their subsidence, that they need to be drained artificially, that is to say, the water falling upon them can be removed only by raising it by artificial means. They lie generally at about five feet below the level of the Amsterdam datum; in the neighborhood of the dunes they range from zero to three feet below A. P. (Amsterdam datum). The lowest are over six feet below this level. The older fen-layers, which are partly covered with river-clay and are entirely converted into polders,

are generally at a higher level, or from 1.5 to 4 feet below A. P. In the vicinity of Delft the lowest polders of Holland are at an average of six feet below the Amsterdam datum.

In many polders of the fen deposits of Holland the peat has in the lapse of time been all dug out, and these polders are said to have been disfenned. The layer of peat, from seven to thirteen feet thick, was valuable as fuel. In this way some polders were converted into shallow lakes or pools of water and remained such. This sort of fen removal, where there is no obligation upon the owners to drain the lakes thus originating, is no longer permitted. The transient benefit of making peat may be followed by a far greater advantage of a permanent nature in the removal of the water and the cultivation of the old sea-bottom. Therefore, for a long period no permission has been granted to remove the fens except under the condition of draining the basin subsequently. At present, in order to meet the cost of draining, a fund must be collected from the sale of the peat, and there must be a guaranty fund also for the proper removal of the fen, the construction of surrounding dikes, the pumping out of the water, &c., during the time that the land is being gradually converted into a lake. After drainage, all charges are paid by the proprietors and the guaranty fund is returned.

There are lakes, such as formerly the Harlem lake, the South Pool, and the great multitude of lakes in North Holland, as the Purmer, the Wormer, the Schermer, the Beemster, &c., from which the fen has been removed in part or wholly by the action of the water in storms in the course of centuries.

If these lakes have a good subsoil, which is generally the case, they are drained not only for the profit from the peat, but for the sake of the soil thus gained, and also because these lakes are sometimes sources of danger to the adjacent country. Thus, in November, 1836, the Harlem lake was blown over its banks to such an extent that it threatened Amsterdam, and in the latter part of the same year it overflowed its borders in another direction and inundated 20,000 acres of land and a part of the city of Leyden. The bottom of the drained lakes consists in general of a layer of sea-clay, from three to six feet thick, but in some localities the layer is very thin, and large spots are occasionally met with where the sand lies exposed—the original floor of Holland's inner sea.

Droogmakeryen are polders from which the turf has been removed

by natural or artificial means, and generally are depressions with the bottom at a level of twelve to eighteen feet below the Amsterdam datum.

After drainage these lands also show a subsidence of the surface, especially when some thin, peaty substance rests on the bottom. A *droogmakery* is thus always a polder, but a polder is not always a *droogmakery*.

The oldest one in South Holland is the Zoetermeer polder, east of The Hague, drained in 1614. By far the greater part in this province dates from the eighteenth and nineteenth centuries.

In North Holland, the most important of these drainage works originated during the rise of the republic, 1610 to 1650.

Some of these drained districts have been inundated and drained a second time, and a few more than once, as, for example, the Bylmer lake. The Naarder lake was inundated in 1629 for the defense of the country, but was not afterwards drained.

In draining these lakes, the first work is to separate them from the surrounding land and water. This is done by constructing a ring-dike around the lake or by utilizing the high roads or banks already in existence, after improving them and raising them somewhat. The earth for the ring-dike must sometimes be brought in part from elsewhere, but it is generally obtained by digging a trench, running all along the ring-dike, on the outside of it, which also serves as the means of communication, instead of that broken off by isolating the lake. This ditch receives the water pumped out of the lake in the process of draining, and during the subsequent continuous exhaustion of water to keep the polder dry. Sometimes the water is transferred at once to other already existing streams, to be conveyed by them towards the open river or to the sea. Many difficulties are often encountered while the work of draining is in progress, mostly of a technical nature, among others is the circumstance that buildings standing upon land in the immediate neighborhood of the lake, or upon the islands within its circuit, are in danger of collapsing, as the bottom whereon they rest will miss the resistance of the water after the drainage. Precautionary measures are therefore necessary, or else compensations for damages. There is also need to provide in other ways for the drawing off of the polder-waters if the lake to be drained had served as a receptacle for the water from polder lands. Again, account must be taken of the fact that in case the ground

under the ring-dike is of a sandy nature, the water will percolate back under the dike into the polder again from its higher level in the *ring-trench.*

Drainage was effected formerly by means of water-mills driven by the wind. At present the work is done much more speedily by means of steam engines. These engines serve later for keeping the polder dry.

As soon as the surface begins to appear a commencement is at once made of parceling out the polder, that is to say, the digging of the necessary drains or ditches, which cut up the polder into regular parts (parcels). The drains (or ditches) are intended to conduct the water falling upon the polder conveniently to the draining (pumping) engines, which stand about the circumference, and which are to keep the polder-waters at a given level below the surface of the ground. The mill-drains, from 26 to 39 feet wide, run direct toward the engines; the water runs into these through drain-ditches, from 19 to 26 feet wide, and at equal distances from each other; crossing these again are the parcel ditches, 11 to 16 feet wide, at distances of 100 to 200 metres apart, which, with the drain-ditches, determine the "parcels" or lots. Between the lots or parcel-ditches, and parallel to them, there are division or fence-ditches, 3 to 4 feet wide, which divide the parcels into three or four lots each; and finally between these and parallel to them are the gutters, about a yard wide. The last-named divide the lots into fields or meadows, and facilitate the sinking away of the water. The superficies of all the ditches amounts from to one-tenth to one-twelfth of the entire polder. The first harvest (usually of colza), mostly very abundant, is obtained by bending down the luxuriant weeds, covering this with the slime from the ditches and then sowing.

The South Holland and Zeeland islands are formed of sea-clay, gradually deposited to the height of high water in the very wide estuaries of the Rhine, the Scheldt and the Maas. The clay lands of Flemish Zeeland and in North Brabant, those from Geertruidenberg to Bergen-op-Zoom, were thus formed by deposits from the sea. In North Holland these lands form the Drechterland district as the oldest nucleus (of that province), and in the north the Anna-Paulowna Polder, the Wieringer Waard, and part of the Zype and the Koegras, &c. These polders, however, especially the two last named, can be compared in value with that of the heavy clay of the Zeeland

islands. The slight difference between high and low water in the Zuider Zee has occasioned the formation of a very thin layer, and here and there none at all or sand only, so that the bottom in such places was nothing but bare sand. Again, sea-clay deposits constitute the clay lands of Texel and Wieringen islands, and of the broad strip of land in Friesland and Groningen along the Zuider Zee, the Wadden and the Dollard, where, as in Zeeland, new territory is still in our day constantly reclaimed from the sea, in connection with which the deposit of clay at low tide is promoted somewhat by artificial means. * * *

Exclusive of this sort of reclaimed lands, such as the Drechterland district of North Holland, and those in Friesland and Groningen, where mounds indicate the existence of a population in very remote times, the sea-clay districts, conquered from the sea, amount to 840,000 acres (350,000) hectares.

If these clay lands are surrounded by comparatively low dikes, as is still done in the Biesbosch (southeast and near Dordrecht), they can be sown and harvested only at certain times of the year, being for the remainder of the time submerged, whereby the level of the surface is raised and their fertility is increased.

All these clay lands are thus also polders, sometimes called sea-polders to distinguish them from the others, and more generally still called *bedykingen* (diked-in lands).

From a hydrographic standpoint there is in general no difference between sea-polders and other polders. The former, however, are often drained *directly* into the sea or the main rivers, whereas in the case of the latter this cannot generally be done. The most of the sea-clay polders get rid of their accumulated waters through natural channels, in which respect they differ from nearly all *non-sea-polders*, whose waters must be raised and discharged by artificial means. The more recent sea-polders, and those which are still daily reclaimed, have so high a surface-level that they can discharge their water naturally at ebb tide, being mostly above, or at, or not much below high-water mark. The older ones, however, have settled considerably, like the fen-polders, and to a depth of about six feet below the Amsterdam datum. This shrinking, in some very recent polders, formed in estuaries where no very high tides occur, requires the use of steam engines or wind-mills immediately after their formation, in order

to raise and discharge their water. The sunken sea-polders occupy, therefore, in this respect, the same position as the fen-polders and the river-clay polders.

ATMOSPHERIC PRECIPITATION AND EVAPORATION.

From observations made on the rainfall at Zwanenburg, near Amsterdam since 1743, it is found that there is on an average eight inches more of rainfall than of evaporation. In the months April to August, inclusive, the evaporation is usually in excess of the rainfall. But the amount of water to be raised is dependent upon the rainfall per month, or in a given storm, and has no reference to the amount which may be evaporated.

DRAINAGE, OR REMOVAL OF THE WATER.

On account of the low situation of most of the polders the water has to be removed by artificial means, and in the case of many the excess of water has to be raised to a great height, since the large rivers and the sea are from fifteen to nineteen feet above the level of the water in many polders, that is, in most of the drained lake-basins.

The sea, or the open rivers flowing into the sea, which in the end receives all polder-water, is termed, generally, the "outer water."

All the other bodies of water in the provinces of North and South Holland and Utrecht, west of Vecht, are land-locked, and are called the "inner water." The height of the outer water may render it impossible for the inner waters to be discharged into them, except at low tide. Where steam engines are in use, as they are at all important points, this discharge is possible at ordinary tide-levels, and extraordinary tides only can interfere.

The inner waters, falling into the polders and drained lake-basins sink into the soil to the level of the ground-waters and then flow out into the *gutters*, ditches and drains which traverse the polder, and of which there should be a great number, equal to one-tenth or one-twelfth of the surface of the polder, in order to carry off the water properly. In these ditches the polder-water must be kept below the surface of the ground from twelve to twenty inches for pasture or meadow, and from twenty inches to three feet for grain-fields, so that the roots may have sufficient moisture and yet not be constantly in

the water. Especially towards spring the effort must be made to maintain this level, which level is called the summer level of the polder, and it differs for each polder according to the height or the use to which the ground is put, and for most polders it is officially determined by the directing or controlling body which nearly every polder possesses.

In many polders there is also a winter level, lower than that for the summer, because in winter there may be a great increase in the volume of the water within a short time. In some polders the winter level is as low as the bottom of the ditches.

As soon as the water in the ditches begins to rise above the proper levels the water of the polders which cannot be discharged naturally is at once pumped up into the outer water. As not all of the polder-land lies immediately near the outer water, provision must be made for pumping its water into a basin at a higher level which is quite shut off and still. This consists of canals expressly dug for that purpose, the ring-trenches around some polders, used mostly in draining lakes, of ship canals, or of former rivers, such as the old Rhine, the Amstel, &c., which, from the very use thus made of them, have lost the character of rivers proper.

For the most part more than one and frequently a great number of polders have their waters pumped into such a system, so to speak, of elevated waters, whose surface has a common level. The water elevated above the polders, shut off by locks, and into which the polder-water is pumped and held temporarily, is called a "boezem."

In case of large boezems, there is sometimes some inter-communication, especially where at one end they have a great influx of water from other boezems, running streams, &c., while at the other there is a great outflow.

All lands discharging their water into a certain boezem are said to belong to it, as, for example, the Amstellands boezem, &c., and we might call these lands, therefore, the water-shed of these boezems. Many lands have no boezem, but discharge their water directly into the rivers or into the sea, as in the Zeeland islands. It may also be noticed that some boezems are utilized by a great many polders, as the Rhineland boezem.

It is understood that the elevated boezem waters must be confined within banks or dikes.

From the boezem the water is discharged into the outer water at one

or more points. Thus, all of the Rhineland region discharges at four places. What this discharge signifies may be imagined when it is stated that more than 7,000,000 cubic yards are pumped daily into the Rhineland boezem and then discharged.

Where polders lie low, polder-water cannot be immediately pumped up into the boezem, and in that case it is done by intermediate boezems. The water is pumped from the lower to the higher and discharged from the highest into the outer water.

When the direct discharge from the boezem into the outer water is impossible, a higher basin is constructed, called the high boezem, which is large enough to permit the engines to pump the water from the lower boezem uninterruptedly, even when the state of the tide keeps the latter shut. These high boezems discharge when the water is low outside.

WIND-MILLS—STEAM ENGINES.

The ditches of the polders are crossed by broader ditches and open drains, as was noticed in the description of a *droogmakery*. Some of these drains, broader than others, and from 25 feet to 40 feet wide, called "mill-drains" or "pump-drains," which have free communication with all the other polder-water, run directly towards the pumping-stations.

The mills at these stations are usually placed at the lowest point of the polder, either immediately on or near by the boezem bank, so that the water may readily flow towards them. Large polders have pumping-engines at several points.

In the case of droogmakeryen and of some deep polders the mills cannot raise the water at once into the outer ditch or boezem. Then the mills are placed at different levels and raise the water from one to another; this occurs usually upon two or three different levels, with one mill upon each, the successive mills being called a "gang."

Two principal kinds of wind-mills are in use, the screw-mills and the scoop-wheel mills; the latter are divided into mills with upright and those with inclined scoop-wheels.

Scoop-wheel mills and screw-mills are much used. The latter are used mostly in North Holland, Friesland and Groningen. The scoop-wheel mills are the oldest sort of pumping-engines, the earliest drainage works having been effected by their use. They can raise water about five feet at the utmost but less effectively to a height of

six feet. Screw-mills can raise water ten to fifteen feet. Screw-mills are coming more and more into use, and in many places they are being substituted for scoop-wheel mills. In Friesland the screw-mill is used almost exclusively. There are occasionally *pumping mills,* in which the water is raised by suction in a cylinder; they can raise the water to a height of twenty feet, but they are used very little because of the difficulty in converting the rotating motion of the mill axle into the up-and-down motion of the pumps.

It is known that in the case of the larger wind-mills, in general, only the cap with the axle and its attached beam are set to the wind. The greatest length of these beams, called their flight or sweep, is about 100 feet.

The common large wind-mills are built of wood or brick, the former costing about $12,000, the latter a little more.

The number of mills depends upon the volume of water to be raised, the height, and their capacity. In order to give some definite ideas on this subject it may be stated that in the case of free boezems a mill of 60 feet sweep is able to take care of 1,600 to 1,700 acres, and in case of closed boezems of 1,350 to 1,500 acres, per one metre in height to be raised. In Rhineland there are about 260 water wind-mills for the 145,000 acres, exclusive of the Harlem lake polder which is controlled by steam engines. This statement, however, has little significance, as no matter how small a polder is it must have at least one mill, unless its water be discharged by a neighboring polder.

At present steam-pumps are coming more and more into use, not only for discharging boezems, but also as polder steam-mills to move the polder-water. Where the height to which the water must be raised is great and the polder is of large extent, steam engines may replace wind-mills with profit. One great advantage over the latter is in the fact that the removal of the water is not dependent upon the strength of the wind. According to official records kept near Delft there appear to be only 130 full days of 24 hours which have sufficiently strong winds for working the mills.

The cost of fuel and attendance is not altogether offset by the economy in the use of the wind, and it has happened that the low-lying, Harlem lake polder, whose waters are drained by three steam-mills, had not the least trouble from an excess of water when the polders lying about it much higher in situation were in a floating

condition. An objection to steam-mills in the case of closed boezems is that while it takes much time and fuel to set them going, the discharge may be so quickly effected that there is a loss in fuel and cost of attendance. A polder steam-mill has usually to be operated fifty days in the year, on the average; in normal conditions and under unfavorable circumstances, as much as sixty or seventy days.

The number of steam-mills has been greatly increased within recent years, especially in the provinces of Utrecht and North Holland.

In certain months of the year, particularly from April to August, when the evaporation exceeds the rainfall, there may be a lack of water in the polders, and then water must be allowed to flow into them to provide which the boezem must be supplied in advance from the outer water.

The letting in of water from the boezem, or from the outer water into the polder, is usually effected by means of specially arranged flood-gates or small conduits which are laid along almost every mill and which contain a gate that can be opened in order to let in water. In the case of scoop-wheel mills the little guard-gates can be forced open, when the water will always flow back. Screw-mills sometimes have valves in the sluice-gates and when they are drawn up the water flows back. Sometimes there are conduits or channels for letting in water apart from the mills altogether, as in the Harlem lake polder.

If the boezem itself has not sufficient water to supply the polders they are provided with a supply from the outer water. At the three points which the Rhineland-polders have for the introduction of water there was allowed to flow in 167,000,000 cubic metres of water in 1868, and during a period of nine years an average of 49,000,000 cubic metres per year.

The conditions in Holland are not altogether similar to those of our New Jersey coastal plain. The Dutch have a country lying at the mouths of large rivers, which for ages have been carrying materials from the higher lands of Germany and of eastern France and Belgium towards the sea and depositing them where the current was slackened by the incoming waters of the ocean tides, or in the great inland or interior sea which lay between the coastal line of dunes and the older drift formations on the east. The accumulation of sand, gravel and clay in these comparatively quiet waters has taken place over a belt many miles wide, as can be seen by a reference to the maps of the

Netherlands which show the topographic features of the country. The distribution of these various kinds of materials has, of course, been determined by the lines of currents, along which the coarser sands and the gravels have been spread, and the areas of more quiet water where the clays were laid down. These large streams have brought down an immense quantity of both coarse and fine material, and the latter has been spread over a wide sea-bottom.

On our New Jersey coast there are no large streams flowing to the ocean. The Delaware is not comparable with the Rhine, nor the Raritan with the Scheldt, although both of them transport a great deal of fine clay from their water-sheds into the bays of the same name. The other Atlantic coast streams are not rapid-flowing and carry much less material in suspension, partly owing to the forested nature of their territory. The sediment thus brought down to the sea by these streams is therefore not comparable to that of the large rivers which flow across the Netherlands, and the accretions from this source are apparently small. Nor has it been of considerable extent since the last glacial epoch or within the Pleistocene time of geologists. There is no evidence that it has been important within the historic period, as was the case in the Netherlands.

The belt of tide-marsh land along our coast, within the dune hills and lying at tide-water level, is comparatively narrow, being from one-half to seven miles wide.

Another difference between our tidal-marsh lands and the lowlands of the Netherlands is in the greater extent and thickness of the deposits of peat in the latter country than in the wet lands of our coastal belt. The accumulation of peat has not been of importance as a deposit anywhere except in some of the swamps which are on the higher parts and above the level of tide, and in them there is so much woody matter from the fallen timber that it is not a true peat, but rather what may be called muck. In the Netherlands there are large deposits of true peat, where it is dug and is used as fuel. The removal of the peaty layer leaves a more solid earthy formation as the basis of a soil. It may be sand or gravel and sand or clay. The clay makes the more fertile lands for agriculture. They are known as sea-clay and as river-clay lands, according as they have been made by deposition of clay in the sea or lakes or along streams and in stream valleys. The tidal lands of New Jersey are clay, clay and peat mixed, and peaty or swampy bottoms. Wherever trees have grown, as for-

example, in the cedar-swamp which bordered the Newark turnpike between the Passaic and the Hackensack rivers and the Pennsylvania railroad, there was an accumulation of vegetable matter, largely in the form of fallen timber, with the sediment brought in by the streams, and the blue mud is there found mixed with more or less peaty or woody matter. On the lower land and where the surface was open and exposed to overflow of the salt or brackish water, and where trees and shrubs would not grow, the waters deposited the fine silt or clay. This deposit is known as the blue mud of the meadows.

The average yearly rainfall in the Netherlands is 27.4 inches, or 62 per cent. of that of New Jersey. Hence the amount of water to be raised from that source alone would be proportionately greater than it is there. The average loss by evaporation is greater from March to September than the rainfall, and the pumping is then reduced to a minimum. Water has to be let in from the canals to maintain the proper level in the canals and in the ground for some crops. The heavier and more torrential rains of our summer storms, although in part offset by greater evaporation due to greater summer heat, would make it necessary to provide larger pumping power than in Holland.

As in the Netherlands, there is an important difference between the clay or blue-mud areas of the meadows and the swampy bottoms or where peat and clay are mixed, and in the reclamation of these low-lying lands this distinction is to be noted, since the same methods are not applicable to all. The clay lands are more readily reclaimed and made arable than the peaty portions.

The tracts of tide-marsh land in the State may be grouped in several well-marked natural divisions, as follows:

1. *Hackensack and Newark meadows.*—From Newark bay the tide-marsh extends northward, in a belt about five miles wide, stretching west from the Hackensack river to the Arlington ridge. To the north the belt is cut into two parts by a tongue of upland at Secaucus, and the Snake hill marks the southern end of this uplift in the meadows. Englewood and Hackensack are about the limits of this tract of marsh land. The meadows southeast and south of Newark and bordering Newark bay on the west to Elizabeth, are properly a part of this natural division. The Passaic and the Hackensack rivers flow through tidal lands and reach the Newark bay in it. Area, 26,890 acres.

2. Kill von Kull and Woodbridge meadows.—There is a strip of marsh of irregular breadth, bordering, as a fringe, the upland from Elizabethport southwest to Perth Amboy. Woodbridge creek flows through it. The area is 4,252 acres.

3. Raritan river meadows.—From New Brunswick to the mouth of the Raritan river there is a nearly continuous belt of tidal-marsh land. A part of the same tract runs up along the South river to Washington. The large body of it is north of the river and opposite Sayreville. Area, 4,715 acres.

4. Chesquake creek, Matavan creek and other small tracts on Raritan bay.—These tracts are indentations of the upland, from one to three miles in length, and roughly triangular in area. The aggregate area is 3,582 acres.

5. Atlantic coast belt.—Along the ocean the upland reaches to the water at Long Branch and there is a notable absence of the dune-range or beaches and of tidal meadows. Excepting some small tracts fringing the sides of the streams where they widen out into shallow bays, as along Shrewsbury river and at Sea Girt and Manasquan, there is no marsh on the eastern Monmouth coast. The main body of marsh land may be said to stretch southward from Point Pleasant, and to be continuous to Cape May. From it there are wide arms running up along the Mullicas and the Great Egg Harbor rivers, and shorter and narrower strips along the smaller streams. A feature of this coastal plain is the range of sand hills or dunes, known as *beaches*, which border the ocean and stand in front of the meadows. This range is narrow, generally less than a mile in breadth, and nowhere more than three miles. The hills are lower and the range is narrow as compared with the coastal range of dunes of the Netherlands. Many small bodies of water, bays and sounds and thoronghfares lie in this belt of marsh land, and the Barnegat bay, Great bay, Great Egg harbor, Absecon bay, Leaming's sound are some of the larger water areas in it. Nearly one-half of this division is occupied by the surface of these many bodies of water. The area of land surface—that is, of tidal marsh—from Point Pleasant to Cape May, is 151,012 acres. The widest part is along the southern end of Burlington and the eastern side of Atlantic counties. From Absecon to Atlantic City it is five miles across the belt, and it is nearly four miles wide all the way thence southward to Cape May.

6. *Delaware bay and Delaware river.*—The marsh lands included

in this division are in several separate tracts along the larger creeks and rivers tributary to the Delaware from the Crosswicks creek, near Trenton, south to the bay. They are generally narrow, although in some cases they extend up the streams several miles. Along Salem creek the marsh begins at Course's Landing and continues for twelve miles along it to the river. The Cohansey and the Maurice rivers also are remarkable for the long distance through which they flow between tide-marsh borders. The upland border is unlike that on the Atlantic side of the State in its greatly irregular course, and necks and points of the upland extend far into the meadows in places, separating long, bordering stretches of tide marsh. There is an absence of features of sounds and bays and, to some extent, of tidal channels, known as thoroughfares. The streams from the upland meander through the more solid meadow land. The outer border or reef of sand is also here wanting and there is no sand-beach of notable extent as on the ocean side of the State. The greatest breadth of this belt of marsh is at Egg Island Point, Cumberland county, where it is five miles wide, from upland to bay. The aggregate area of tide-marsh lands along the Delaware river from Trenton to Salem is 26,767 acres. Between Salem and Cape May the area is 79,282 acres.

The total tide-marsh area as thus grouped is as follows:

1. Hackensack and Newark meadows	26,890	acres.
2. Staten Island sound and Woodbridge	4,252	"
3. Raritan river	4,715	"
4. Chesquake, Matawan, Raritan bay	3,582	"
5. Atlantic coast belt	151,012	"
6. Delaware river and bay	106,049	"
	296,500	"

There are great differences in the degree of exposure to the force of the storm-tides and to wave action in these several groups—those which lie along the tributaries of the Delaware being least exposed to such agency. Along Delaware bay the tidal action is less energetic and violent than on the ocean front. The Hackensack and Newark meadows also are more distant from the inrush of storm-tides, and therefore more protected, although the rise of the tides is probably as great as on the more exposed ocean front, and in the Atlantic coast belt or division there is a wide difference between the localities, as for example, the meadows along the streams and those on the larger

sounds and bays. Again, the dune hills serve to protect, in a notable degree, the fringes of marsh which lie against their inner side.

The character of these marsh lands, viewed from the standpoint of reclamation, is affected largely by the shape of the land areas and the location of the water. In parts of the Atlantic belt, as in Cape May, there are so many bays and sounds and such a network of tidal-waters that the water front or border bears a large ratio to the land area. This feature of excessive tidal-ways is to be seen in all of these groups and there is a wide diversity in this respect within short distances or in adjoining tracts. The meandering courses of some of the creeks make double the actual length of the stream in many cases—as the Cohansey creek, the Salem creek, Mullicas river and others. This feature would, of course, involve a correspondingly larger expense in constructing dikes and in maintaining a defense against the outside waters. The facility of the discharge of the water from the reclaimed or embanked plots and tracts is, however, promoted by an increased outflow line and a larger number of sluice-gates, possibly where there are many streams and a longer water front. For discharge by means of pumps this condition might be favorable rather than obstructive. Where heavy and expensive banks or dikes are necessary, the increase in length of waterway and water front means an increase in expenses of construction and of maintenance.

An important difference in conditions is in the nature of the soil and subsoil and underlying deposit. Where the meadows or marshes are of clay they are more solid and less spongy and wet than those where the amount of vegetable matter is large, as in swampy tracts. They are soft, miry and wet, and, on drying, the residue of material, as a basis of a soil for pasture or for tillage, is less than it is in the clayey areas or tracts. As a result, the shrinkage on draining such swampy or peaty meadows is great, and the surface settles so much sometimes that it is impossible to reclaim it without the aid of some artificial means of raising and discharging the water. Of course, the subsidence to the level of low tide is possible without necessitating the resort to pumping out the water, but below that level the natural drainage is no longer possible. Hence it is highly important in reclaiming these tidal lands to select the more clayey and solid tracts and to avoid the peaty parts.

In the Netherlands, the general reclamation projects, which have covered great areas of tidal lands, have been carried forward to

success by the patient industry and persistent energy of a people experienced in the work, but often at great expense, and in part because the subsidence of the surface has made the cost of dike-construction large, and the raising of the water from a lower level to that of tide correspondingly greater than in localities where the surface has not settled so much. The removal of the turf or peat for use as fuel has there afforded a solid base for soil; but the work of removing the superficial peat has not been altogether practicable, and the difficulty in such case, due to subsidence, has been experienced to the increase of expenditures in reclamation of the land. The less value of land here and the greater cost of labor makes it important to consider carefully the kind of soil and the possible shrinkage and subsidence upon the removal therefrom of the waters of the tides. Generally, the more swampy and wet meadows are those away from the waterways and the tide-waters and near the upland. A notable example is in the Newark and Hackensack meadows, on their western side, along the Arlington ridge, between the old Belleville and the Newark turnpikes, and also south of Newark, toward Elizabeth. The incoming waters seem to have deposited their sediment more rapidly along the streams and less at a distance from them, so that the part adjacent to the upland and furthest from the flood-tide has received less of a deposit. In places the wash from the upland has offset the less deposition by the tidal waters. The experience in the State in reclaiming tidal meadows, particularly in Salem and Cumberland counties, has shown that the subsidence is in some cases enough to lower the surface to low-tide level and to make further improvement and successful tillage no longer practicable or profitable; and embanked meadow lands have been abandoned from this cause. Recourse to pumping the water by wind-mill or steam has not been attempted on account of the apparently great expense of raising the water by artificial means. Observation of fresh-water meadows shows subsidence in them to be a source of large expense in their reclamation.

The advantageous location of some of the tide-meadow lands of New Jersey and their nearness to markets and to railways as well as to tide-water or navigable waterways and channels of communication, is worthy of serious consideration in the general question of reclamation. In this respect the situation is not altogether unlike that of the Netherlands, where the large cities of the kingdom are surrounded,

almost, by meadows of the greatest value as pasture lands to large herds of dairy cattle. The dairy industry thrives on these rich grazing districts within sight of the large cities. Thousands of acres of tide meadows in New Jersey which are adapted to pasturage, or, better, to the more profitable business of market-gardening, are within a few miles of New York City and really within the metropolitan district. Other tracts are along the Delaware river and bay, easily accessible by water to and from Philadelphia. Some parts of the Atlantic coast belt are not so favorably situated and their reclamation is dependent upon the conditions which belong to agriculture in general rather than to these branches. The value of rich and fertile lands near Newark, Elizabeth and Jersey City, easy of cultivation and not subject to drought, makes their reclamation a subject of importance, and their nearness to large city population and markets for agricultural products is suggestive of the experiment of reclamation in that part of the State. The value of some of these meadow lands for building-sites, and its possible enhancement in view of the rapid growth of the metropolitan district must not be accepted as a criterion for large tracts, nor should it deter reclamation and improvement. The occupancy by pastures and market-gardens is not obstructive to city extension over them in the future, as the tide of population can flow over them as readily as it has done over the farms of Essex and Union counties to the west and southwest, or Bergen hill on the east. The abandonment of land, capable of raising crops, to the growth of weeds, and to commons because of its prospective value in city lots is to be condemned, both on account of the waste and because it makes an unsightly border around our towns and cities. The contrast in this respect between the cities of Great Britain and Holland and ours is great and suggestive of improvement on our part.

The great extent of unoccupied land in the western part of our country and the uncleared and untilled tracts in the old-settled States, in comparative proximity to the large cities, as well as the large size of farms which allow of partition and division, have all met the want of land for farming purposes, and have to this extent retarded the work of reclamation of wet and of tide-marsh lands. Upland at low prices has competed successfully with these undrained lands, and the latter have been neglected, generally. The cost of diking or embanking adds much to purchase-cost and makes the amount of capital put in land comparatively high for farm use. If to the cost for

banks or dikes there be added the outlay for machinery to raise the water, the aggregate becomes large and almost prohibitory. There is in many localities the necessity for co-operative or associated work, instead of individual enterprise. And this fact has no doubt prevented, in a large degree, the reclamation of the tide-marsh lands in the State. The fertility and the ease of cultivation of these lowlands should attract the attention of farmers and immigrants in search of new land near markets and in old-settled communities.

MINERAL STATISTICS.

IRON ORE.

The statistics of iron ore for the year 1892 have been received through the courtesy of John Birkinbine, of Philadelphia, who collected carefully the amount for each mine and mining company for the use of the Mineral Statistics division of the United States Geological Survey.

The total output of the mines amounted to 465,455 tons. The total reported by the several railroad companies, and by the furnace companies which receive their ore directly from mines, and which is not included in ore tonnage of these companies, amounts to 469,236 tons.

The statistics of last year's report are reprinted here:

IRON ORE.

1790	10,000 tons	Morse's estimate.
1830	20,000 tons	Gordon's Gazetteer.
1855	100,000 tons	Dr. Kitchell's estimate.
1860	164,900 tons	U. S. census.
1864	226,000 tons	Annual Report State Geologist.
1867	275,067 tons	" " "
1870	362,636 tons	U. S. census.
1871	450,000 tons	Annual Report State Geologist.
1872	600,000 tons	" " "
1873	665,000 tons	" " "
1874	525,000 tons	" " "
1875	390,000 tons	" " "
1876	285,000 tons*	
1877	315,000 tons*	
1878	409,674 tons	" " "
1879	488,028 tons	" " "
1880	745,000 tons	" " "

* From statistics collected later.

1881	737,052 tons	Annual Report State Geologist.
1882	932,762 tons	" " "
1883	521,416 tons	" " "
1884	393,710 tons	" " "
1885	330,000 tons	" " "
1886	500,501 tons	" " "
1887	547,889 tons	" " "
1888	447,738 tons	" " "
1889	482,169 tons	" " "
1890	552,996 tons	" " "
1891	551,358 tons	" " "

ZINC ORE.

The production of zinc ore in the State for the calendar year 1892, as reported by the companies working the mines at Sterling Hill and at Franklin Furnace, in Sussex county, amounted to 77,298 tons.

The statistics for preceding years are reprinted in the following statement:

1868	25,000 tons*	Annual Report State Geologist.
1871	22,000 tons	" " "
1873	17,500 tons	" " "
1874	13,500 tons	" " "
1878	14,467 tons	" " "
1879	21,937 tons	" " "
1880	28,311 tons	" " "
1881	49,178 tons	" " "
1882	40,138 tons	" " "
1883	56,085 tons	" " "
1884	40,094 tons	" " "
1885	38,526 tons	" " "
1886	43,877 tons	" " "
1887	50,220 tons	" " "
1888	46,377 tons	" " "
1889	56,154 tons	" " "
1890	49,618 tons	" " "
1891	76,032 tons	" " "

*Estimated for 1868 and 1871. Statistics for 1873 to 1890, inclusive, are from reports of the railway companies carrying the ores to market. The report for 1890 was from the companies working the mines.

PUBLICATIONS OF THE SURVEY.

DISTRIBUTION OF PUBLICATIONS.

The demand for the publications of the Survey has in nowise diminished during the past year. Owing to the uncompleted condition of the rooms of the Survey in the State House, the work of distribution has been carried on by Mr. Upson, as heretofore, from the old office in New Brunswick.

The edition of the first volume of the Final Report (1888) is so nearly exhausted that its distribution must be most carefully considered in the future.

There is a steady demand for the topographical maps, both in single sheet and in atlas form. The sales during the last year amounted to a trifle more than $600.

It is the wish of the Board of Managers to complete, as far as possible, incomplete sets of the publications of the Survey, chiefly files of the Annual Reports, in public libraries, and librarians are urged to correspond with Mr. Upson concerning this matter.

By the act of 1864 the Board of Managers of the Survey is a board of publication with power to issue and distribute the publications as they may be authorized. The Annual Reports of the State Geologist are printed by order of the Legislature as a part of the legislative documents. They are distributed largely by members of the two houses. Extra copies are supplied to the Board of Managers of the Geological Survey and the State Geologist, who distribute them to libraries and public institutions, and as far as possible, to any who may be interested in the subjects of which they treat. Several of the reports, notably those of 1868, 1873, 1876, 1879, 1880 and 1881, are out of print and can no longer be supplied by the office. The first volume of the Final Report, published in 1888, was mostly distributed during the following year, and the demand for it has been far beyond the supply. The first and second parts of the second volume

have also been distributed to the citizens and schools of the State, and to others interested in the particular subjects of which they treat. The appended list makes brief mention of all the publications of the present Survey since its inception in 1864, with a statement of editions that are now out of print. The publications of the Survey are, as usual, distributed without further expense than that of tranportation, except in a single instance of the maps, where a fee to cover the cost of paper and printing is charged as stated.

CATALOGUE OF PUBLICATIONS.

GEOLOGY OF NEW JERSEY, Newark, 1868. 8vo , xxiv.+899 pp. Out of print.

PORTFOLIO OF MAPS accompanying the same, as follows:

1. Azoic and paleozoic formations, including the iron-ore and limestone districts; colored. Scale, 2 miles to an inch.
2. Triassic formation, including the red sandstone and trap rocks of Central New Jersey; colored. Scale, 2 miles to an inch.
3. Cretaceous formation, including the greensand-marl beds; colored. Scale, 2 miles to an inch.
4. Tertiary and recent formations of Southern New Jersey; colored. Scale, 2 miles to an inch.
5. Map of a group of iron mines in Morris county; printed in two colors. Scale, 3 inches to 1 mile.
6. Map of the Ringwood iron mines; printed in two colors. Scale, 8 inches to 1 mile.
7. Map of Oxford Furnace iron-ore veins; colored. Scale, 8 inches to 1 mile.
8. Map of the zinc mines, Sussex county; colored. Scale, 8 inches to 1 mile. A few copies are undistributed.

REPORT ON THE CLAY DEPOSITS of Woodbridge, South Amboy and other places in New Jersey, together with their uses for fire-brick, pottery, &c. Trenton, 1878, 8vo., viii.+381 pp., with map. Out of print.

A PRELIMINARY CATALOGUE of the Flora of New Jersey, compiled by N. L. Britton, Ph.D. New Brunswick, 1881, 8vo., xi.+233 pp. Out of print.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. I. Topography. Magnetism. Climate. Trenton, 1888, 8vo., xi.+439 pp. Very scarce.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part I. Mineralogy. Botany. Trenton, 1889, 8vo., x.+642 pp.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part II. Zoology. Trenton, 1890, 8vo., x.+824 pp.

BRACHIOPODA AND LAMELLIBRANCHIATA of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield, Trenton, 1886, quarto, pp. 338, plates XXXV. and map. (Paleontology, Vol. I.)

GASTEROPODA AND CEPHALOPODA of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield, Trenton, 1892, quarto, pp. 402, plates L. (Paleontology, Vol. II.)

ATLAS OF NEW JERSEY. The complete work is made up of twenty sheets, each twenty-seven by thirty-seven inches, including margin, intended to fold once across, making the leaves of the Atlas 18½ by 27 inches. The location and number of each map are given below. Those from 1 to 17 are on the scale of one mile to an inch.

No. 1. Kittatinny Valley and Mountain, from Hope to the State line.
No. 2. Southwestern Highlands, with the southwest part of Kittatinny valley.
No. 3 Central Highlands, including all of Morris county west of Boonton, and Sussex south and east of Newton.
No. 4 Northeastern Highlands, including the country lying between Deckertown, Dover, Paterson and Suffern.
No. 5 Vicinity of Flemington, from Somerville and Princeton westward to the Delaware.
No. 6. The Valley of the Passaic, with the country eastward to Newark and southward to the Raritan river.
No 7. The Counties of Bergen, Hudson and Essex, with parts of Passaic and Union.
No. 8. Vicinity of Trenton, from New Brunswick to Bordentown.
No. 9. Monmouth Shore, with the interior from Metuchen to Lakewood.
No. 10. Vicinity of Salem, from Swedesboro and Bridgeton westward to the Delaware.
No. 11. Vicinity of Camden, to Burlington, Winslow, Elmer and Swedesboro.
No. 12. Vicinity of Mount Holly, from Bordentown southward to Winslow and Woodmansie.
No 13 Vicinity of Barnegat Bay, with the greater part of Ocean county.
No 14. Vicinity of Bridgeton, from Allowaystown and Vineland southward to the Delaware bay shore.
No. 15. Southern Interior, the country lying between Atco, Millville and Egg Harbor City.
No. 16. Egg Harbor and Vicinity, including the Atlantic shore from Barnegat to Great Egg Harbor.
No 17. Cape May, with the country westward to Maurice river.
No. 18. New Jersey State Map. Scale, 5 miles to an inch. Geographic.
No. 19. New Jersey Relief Map. Scale, 5 miles to the inch. Hypsometric.
No. 20. New Jersey Geological Map. Scale, 5 miles to the inch.

In order to meet the constantly increasing demand for these sheets, the Board of Managers of the Geological Survey have decided to allow them to be sold at the cost of paper and printing, for the uniform price of 25 cents per sheet, either singly or in lots. This amount covers all expense of postage or expressage, as the case may be. Sets of the sheets, bound in atlas form (half morocco, cloth sides, gilt title, maps mounted on muslin, and guarded), are furnished at $13.50 per copy. Application and payment, invariably in advance, should be made to Mr. Irving S. Upson, New Brunswick, N. J., who will give all orders prompt attention.

REPORT OF PROFESSOR GEORGE H. COOK upon the Geological Survey of New Jersey and its progress during the year 1863. Trenton, 1864, 8vo., 13 pp. Out of print.

The Annual Report of Prof. Geo. H. Cook, State Geologist, to His Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1864. Trenton, 1865, 8vo., 24 pp. Out of print.

Annual Report of Prof. Geo. H. Cook, State Geologist, to His Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1865. Trenton, 1866, 8vo., 12 pp. Out of print.

Annual Report of Prof. Geo. H. Cook, State Geologist, on the Geological Survey for the year 1866. Trenton, 1867, 8vo., 28 pp. Out of print.

Report of the State Geologist, Prof. Geo. H. Cook, for the year 1867. Trenton, 1868, 8vo., 28 pp. Out of print.

Annual Report of the State Geologist of New Jersey for 1869. Trenton, 1870, 8vo., 57 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1870. New Brunswick, 1871, 8vo., 75 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1871. New Brunswick, 1872, 8vo., 46 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1872. Trenton, 1872, 8vo., 44 pp., with map. Out of print.

Annual Report of the State Geologist of New Jersey for 1873. Trenton, 1874, 8vo., 128 pp., with maps. Out of print.

Annual Report of the State Geologist of New Jersey for 1874. Trenton, 1874, 8vo., 115 pp. Out of print.

Annual Report of the State Geologist of New Jersey for 1875. Trenton, 1875, 8vo., 41 pp., with map.

Annual Report of the State Geologist of New Jersey for 1876. Trenton, 1876, 8vo., 56 pp., with maps. Out of print.

Annual Report of the State Geologist of New Jersey for 1877. Trenton, 1877, 8vo., 55 pp. Out of print.

Annual Report of the State Geologist of New Jersey for 1878. Trenton, 1878, 8vo., 131 pp., with map. Out of print.

Annual Report of the State Geologist of New Jersey for 1879. Trenton, 1879, 8vo., 199 pp., with maps. Out of print.

Annual Report of the State Geologist of New Jersey for 1880. Trenton, 1880, 8vo., 220 pp., with map. Out of print.

Annual Report of the State Geologist of New Jersey for 1881. Trenton, 1881, 8vo., 87+107+xiv. pp., with maps. Out of print.

Annual Report of the State Geologist of New Jersey for 1882. Camden, 1882, 8vo., 191 pp., with maps. Out of print.

Annual Report of the State Geologist of New Jersey for 1883. Camden, 1883, 8vo., 188 pp.

Annual Report of the State Geologist of New Jersey for 1884. Trenton, 1884, 8vo., 168 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1885. Trenton, 1885, 8vo., 228 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1886. Trenton, 1887, 8vo., 254 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1887. Trenton, 1887, 8vo., 45 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1888. Camden, 1889, 8vo., 87 pp., with map.

Annual Report of the State Geologist of New Jersey for 1889. Camden, 1889, 8vo., 112 pp., with cut.

Annual Report of the State Geologist of New Jersey for 1890. Trenton, 1891, 8vo., 305 pp., with maps.

Annual Report of the State Geologist of New Jersey for 1891. Trenton, 1892, 8vo., xii.+270 pp., with map and cuts.

Annual Report of the State Geologist of New Jersey for 1892. Trenton, 1893, 8vo., x.+368 pp., with maps.

INDEX.

A.

B.

C.

D.

M.

N.

O.

P.

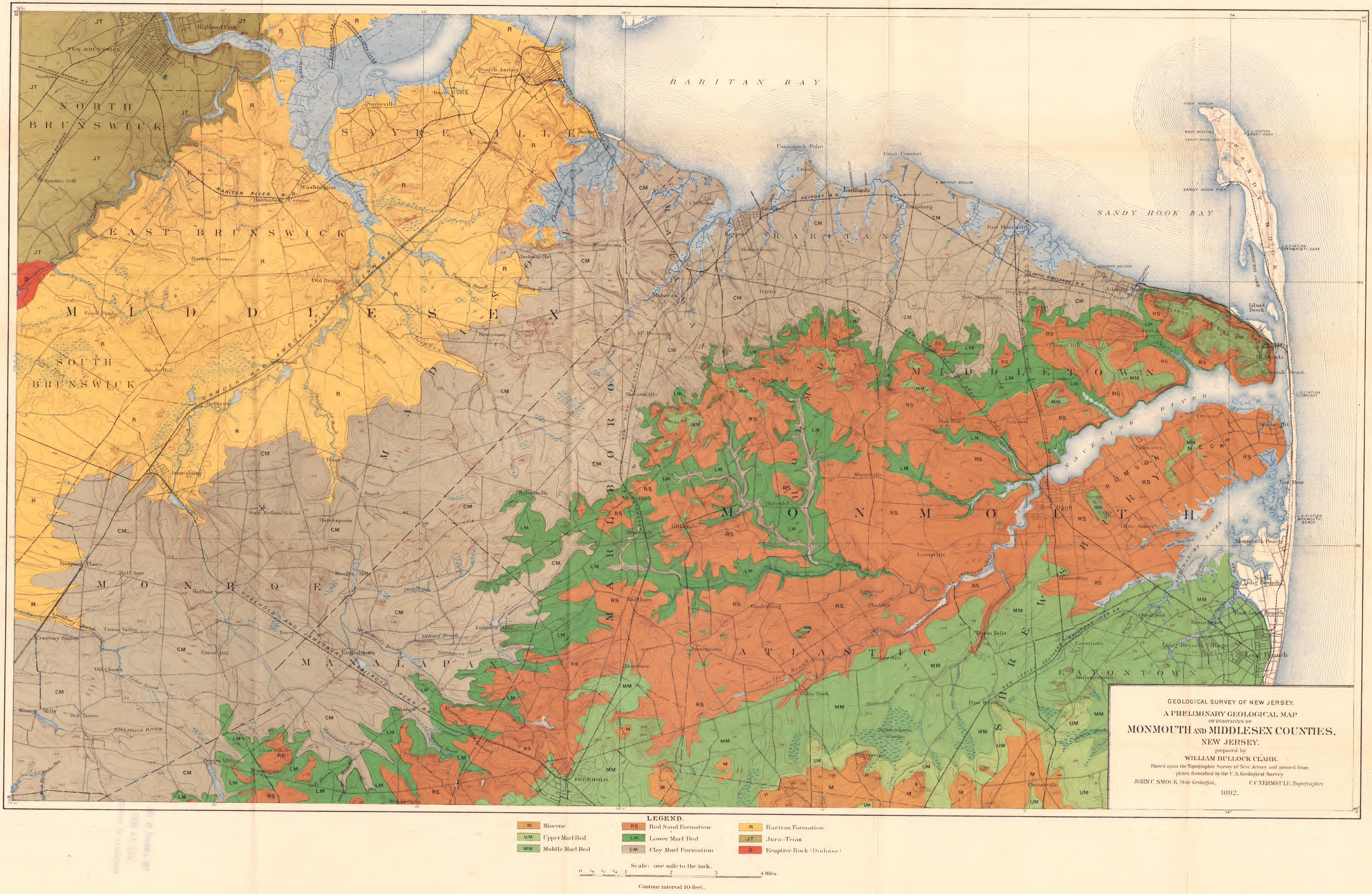
U.

V.

W.

Z.


M
UM
110



GEOLOGICAL SURVEY OF NEW JERSEY.
A PRELIMINARY GEOLOGICAL MAP
OF PORTIONS OF
MONMOUTH AND MIDDLESEX COUNTIES,
NEW JERSEY.
prepared by
WILLIAM BULLOCK CLARK.
Based upon the Topographic Survey of New Jersey and printed from plates furnished by the U.S. Geological Survey
JOHN C. SMOCK, State Geologist,
C.C. VERMEULE, Topographer.
1892.
RARITAN BAY
SANDY HOOK BAY
NORTH BRUNSWICK
EAST BRUNSWICK
SOUTH BRUNSWICK
SAYREVILLE
MIDDLESEX
MONROE
MANALAPAN
MARLBORO
MATAWAN
RARITAN
MIDDLETOWN
MONMOUTH
ATLANTIC
SHREWSBURY
EATONTOWN
RUMSON NECK
NAVESINK RIVER
SHREWSBURY RIVER
NEW BRUNSWICK
South Amboy
Matawan
Keyport
Red Bank
Freehold
Long Branch
LEGEND.
M Miocene
UM Upper Marl Bed
MM Middle Marl Bed
RS Red Sand Formation
LM Lower Marl Bed
CM Clay Marl Formation
R Raritan Formation
JT Jura-Trias
D Eruptive Rock (Diabase)
Scale: one mile to the inch.
0 1/4 1/2 3/4 1 2 3 4 Miles
Contour interval 10 feet.


GEOLOGICAL SURVEY OF NEW JERSEY
J.C. SMOCK, STATE GEOLOGIST.
A MAP OF
NEW JERSEY
To accompany the ANNUAL REPORT of the
STATE GEOLOGIST
FOR
1892.
From original Surveys
by C.C.VERMEULE, Topographer.
based on the
TRIANGULATION OF THE U.S. COAST AND GEODETIC SURVEY.
Scale: 5 miles to an inch
MILES
KILOMETERS
HACKENSACK
POMPTON
ROCKAWAY
SOUTH BRANCH
LAWRENCE BROOK
MIDDLE BROOK
ATLANTIC OCEAN
LONG ISLAND SOUND
DELAWARE BAY
LEGEND
Pumping Stations
Water-Sheds now in use on Atlantic Slope
Water-Sheds, available for supplying
Northeastern Cities.